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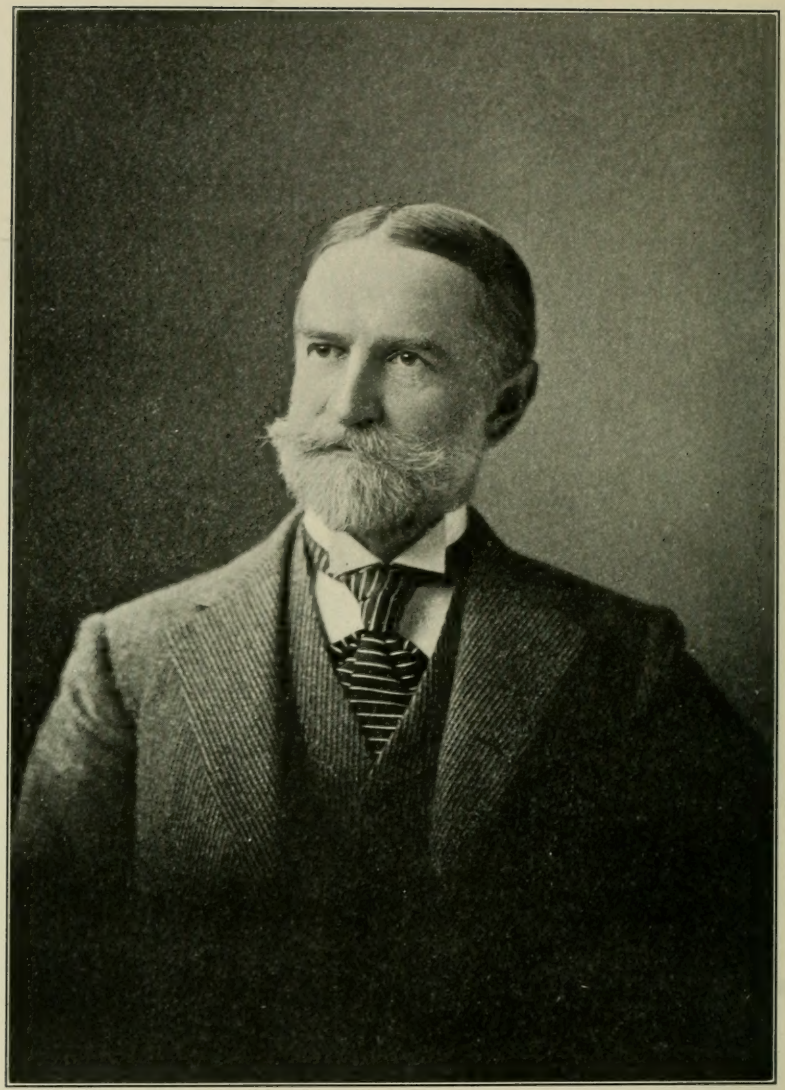

Samuel T. Sadtler

Tech
Chemical Engineering Progress

TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

CHEMICAL ENGINEERS

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VOLUME I

1908

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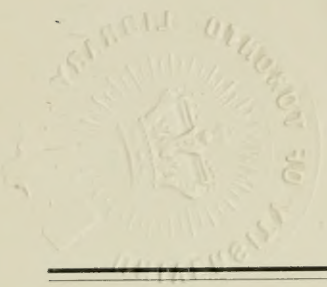
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Preliminary Discussion

on the

Advisability of Organizing

the

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

The first suggestion to form the present Institute of Chemical Engineers was made by Richard K. Meade, of Nazareth, Pa. Early in the year 1907, he sent out a letter of inquiry to about 50 chemists, most of whom were engaged in industrial work, asking them if they thought it desirable to organize an Institute of Chemical Engineers. As a large proportion of the replies received to this letter were favorable towards the formation of such a society, Mr. Meade called a meeting of those interested in its formation to be held in Atlantic City, June 21st, in connection with the meeting of the Society of Testing Materials.

About 15 to 20 chemists reported and met at the Hotel Chalfonte, at five o'clock June 21st. Chas. F. McKenna was appointed temporary chairman and William M. Booth temporary secretary. A discussion of the question as to whether it was desirable to organize a society of chemical engineers indicated that there was considerable difference of opinion as to whether the most favorable time had arrived for forming such a society. Further discussion by a larger number of chemists seemed desirable before proceeding to add one more to the already numerous chemical societies. A committee was, therefore, appointed of which Chas. F. McKenna was chairman, William M. Booth, secretary, the remaining members being J. C. Olsen, Arthur C. Little, Richard K. Meade, and William M. Walker. This committee drafted the following circular letter which was mailed to about 600 prominent chemists in the United States and Canada.

New York, Sept. 3, 1907.

Dear Sir—

At Atlantic City, June 21, 1907, a number of chemists, mostly members of the American Society for Testing Materials, met and discussed the advisability of forming a society to be composed of trained chemists who are designing, constructing, managing or controlling establishments involving the application of chemical principles to the treatment of raw materials or doing work having an intimate connection with such operations; such a society to have a high standard of admission somewhat similar to the requirements of membership for the American Society of Civil Engineers. (Ten years of practical experience, five of which being in a responsible position. Age limit for Junior Members 20 years, for Senior Members 30 years.)

The general opinion of those present at this meeting was that the formation of such a society would tend to raise the standing of chemists among manufacturers and that many other advantages would accrue, among which the following were mentioned by various speakers:

a. Raising the standard of education of chemists.

b. Raising the ethical standard of the profession.

c. Encouraging bold and original work by members.

Quarterly national meetings were suggested to avoid the evils of localized control.

Some doubt was expressed as to whether the time had come for the formation of such a society because of possible detriment to the present very excellent chemical societies, and also as to whether there is a general desire among chemists for its organization.

A committee was appointed to present the matter to a large number of American chemists and obtain their opinion as to the advisability of the formation at this time and the conditions of membership of such a society.

This committee, therefore, addresses you and asks your opinion with reference to the following:

1. Do you consider the formation of such a society advisable?

2. In your opinion is an organization on such lines likely to afford any special and important advantages?

3. Do you believe these advantages would continue in the future?

4. Would you favor the use of the title—American Society of Chemical Engineers?

5. Would you favor a high standard of admission?

6. Would you favor an age limit for membership, 30 for instance?

7. Would you favor Junior and Senior grades of membership?

8. Would you favor a membership test by education, career or achievement, any or all of these?

The committee will appreciate an early reply and a full statement of your views on the questions asked and any other pertinent suggestions which you may wish to offer.

CHARLES F. MCKENNA, *Chairman,*
221 Pearl St., New York, N. Y.
WILLIAM M. BOOTH, *Secretary.*
Syracuse, N. Y.
JOHN C. OLSEN,
Polytechnic Institute, Brooklyn, N. Y.
RICHARD K. MEADE,
Nazareth, Penn.
WILLIAM H. WALKER,
Institute of Technology, Boston, Mass.
ARTHUR D. LITTLE,
93 Broad St., Boston, Mass.

About 187 replies to this letter were received. Seventy per cent. of those who expressed a positive opinion were in favor of forming the proposed society; 87 per cent. of those who replied were strongly in favor of a society of high entrance requirements, if it should be organized.

The Committee of Six concluded from the discussion and correspondence that the larger proportion favored the following propositions:

First—The proposed organization should be called the American Institute of Chemical Engineers.

Second—The Institute should not attempt the publication of a journal, but should confine its publications to a volume or volumes of transactions.

Third—None of the existing journals should be designated as the official organ of the society, but members should be free to publish articles wherever they chose.

Although the result of this vote was in favor of forming the proposed organization, the Committee of Six felt that it was too limited in number to finally cast the deciding vote for or against the incor-

poration of the new society, and that further opportunity for discussion of the question should be given, after which a vote should be taken of those who had participated in the discussion. For this purpose fifty chemists, who were prominent in the field of applied chemistry, were invited to join them in a discussion and final decision of the questions so far raised. The fifty men chosen included men who were strongly in favor of the proposed organization, some who were strongly opposed and others who had expressed no opinion in the matter.

COMMITTEE OF FIFTY

E. G. Acheson
C. E. Acker
Jerome Alexander
Peter T. Austen
A. Bement
M. T. Bogert
W. H. Bassett
T. L. Briggs
J. M. Camp
Chas. F. Chandler
W. M. Chauvenet
Alan A. Claflin
M. H. Clark
W. W. Daggett
C. B. Dudley
J. W. Ellms
Herman Frasch
Wm. M. Grosvenor
Edward Gudeman
Albert P. Hallock
N. F. Harriman
Edward Hart
R. C. Hoffman
W. D. Horne
Henry Howard
L. S. Hughes
A. C. Humphreys
W. R. Ingalls
H. W. Jordan
H. E. Kiefer
Karl Langenbeck
A. C. Langmuir
Waldemar Lee
N. W. Lord
A. Lundteigen
Wm. P. Mason
Wm. McMurtrie
J. D. Pennock
Andrew Robertson
Rudolph de Roode
S. P. Sadtler
F. Schniewind
Thorn Smith
F. G. Stantial
T. B. Stillman
Maximilian Toch
J. Edward Whitfield
W. R. Whitney
M. C. Whitaker
F. G. Wiechmann

The Committee of Six, together with sixteen members of the Committee of Fifty, met in New York at the Hotel Belmont, Jan. 18, 1908, and discussed the advisability of organizing the society of Chemical Engineers. In the early part of this meeting the following motion was made by Dr. Wiechmann: "It is deemed to be the opinion of the present committee that an Institute of Chemical Engineers be formed." The discussion during the remainder of the evening was carried out on this motion. During the discussion a list of requirements for membership in the proposed Institute, which had been drafted by the Committee of Six, was read by the Secretary. These proposed requirements were very similar to those afterwards adopted for the Constitution of the Institute. It was stated at the meeting, and subsequently

in a letter to the Committee of Fifty, that the Institute was to be a society of trained specialists, practicing in fields where chemical knowledge was demanded, and also skill in designing, constructing and operating establishments carrying out chemical processes, and that men who could not meet these requirements would not be admitted. Further, that all details of organization would be decided upon later. No vote was taken at the Hotel Belmont meeting upon Dr. Wiechmann's motion. The members present, however, decided by a unanimous vote that a report of the discussion should be sent to all members of the Committee of Fifty and that a vote should be taken on Dr. Wiechmann's motion by mail.

The final vote of this committee stood as follows:

Affirmative	22
Negative	7
Neutral	7
Had not had time to consider	2
One member abroad	1
One death	1
Total	40

The Committee of Six considered this vote as a mandate to organize the American Institute of Chemical Engineers. They therefore issued a call for a meeting to be held at Philadelphia, June 22d, 1908, for the purpose of organization. An invitation to be present at this meeting was sent out to all chemists who had expressed themselves as interested in the formation of the proposed society, the committee being careful to invite only such men as they had reason to believe could qualify as members of the proposed society.

MINUTES OF THE PHILADELPHIA MEETING FOR ORGANIZATION

HELD AT THE ENGINEERS' CLUB,
JUNE 22, 1908.

Dr. Chas. F. McKenna called the meeting to order at 10.30 A. M., and introduced Dr. Samuel P. Sadtler, who welcomed the visitors and spoke of the chemical manufacturers of the vicinity:—explosives, textiles, petroleum refining, linoleum, metallurgical industries, morocco, ammonia and glycerin.

Dr. McKenna was elected temporary chairman, and Dr. David W. Horn, temporary secretary.

Mr. Booth, Secretary of the Committee on Organization, read the report of that committee. Messrs. Ingalls, Meade and Alexander were appointed a Committee on Credentials, and after listening to an address from the Temporary Chairman, Dr. Chas. F. McKenna, reported, recommending that all those present be entitled to a vote as chemical engineers. The report was accepted.

Messrs. Olsen, Grosvenor, Renaud, S. P. Sadtler and Whitfield were apointed a Committee on Constitution.

Messrs. Wiechmann, Adamson, Dannerth, Whitfield and Trautwein were appointed a Committee on Nominations.

Messrs. Ehrenfeld, S. P. Sadtler and Hunicke were appointed a Committee on Finance.

After a short impromptu address by Dr. Hunicke the meeting adjourned until 3 P. M.

AFTERNOON SESSION, 3 P. M.

The report of the Committee on Constitution was then presented by the Chairman, Dr. Olsen. The Constitution was discussed in detail, section by section, and a number of amendments made both in the form of expression and the subject matter. As this was the most important part of the work of the meeting, the remainder of the afternoon was devoted to it. The Constitution as amended was finally adopted as a whole.

The Committee on Nominations reported in favor of the election of S. P. Sadtler, President; Chas. F. McKenna, H. A. Hunicke and E. G. Acheson, Vice-Presidents; Wm. M. Booth, Treasurer; J. C.

Olsen, Secretary; R. K. Meade, Auditor; Ludwig Reuter, Thorn Smith and H. F. Brown, Directors for one year; Eugene Haanel, J. M. Camp, C. A. Catlin, Directors for two years; G. P. Adamson, David Wessen, Edward Gudeman, directors for three years, and they were elected.

Dr. S. P. Sadtler then took the chair and addressed the meeting.

It was voted that the bills contracted in organization be assumed by the Institute.

It was voted that the dues for the first half-year (June 1st-December 1st, $7.50) be collected by the Treasurer.

A vote of thanks to the Engineers' Club for the use of their room was adopted, and a vote of thanks to those members who took part in the preliminary organization was adopted. The meeting adjourned to meet at an informal session at 8 P. M., at which time no business was transacted. The Membership Committee was appointed by President Sadtler, and a number of other details were discussed and decided upon. Adjourned.

THE JUSTIFICATION OF THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

AN ADDRESS DELIVERED BY CHARLES F. MCKENNA AT THE PHILADELPHIA MEETING, JUNE 22, 1908.

We have gathered in the City of Brotherly Love to perform an act which is brotherly to the utmost. We have come here to establish a society which shall bring together as brothers a group of men who have felt themselves to be closely related, who have been calling to one another to approach, to come under one banner, stand shoulder to shoulder in mutual support, and to enjoy all the inspiration that comes from mingling with one's fellows.

This call has been heard at various times, abroad for twenty-five years and in this country for over ten years past. It grew in clearness and volume during very recent times, and has culminated in the gathering in which we are now so happy as to participate. We know it was not without misgivings and hesitation that the answer to this call was first returned, but we are confident now that the misgivings were unfounded and the hesitation unwarranted.

It has been a subject of frequent remark, of an opinion almost unanimous, amongst those discussing this scientific society during the past year, that there appears to be enough of such organizations in this country.

The followers of almost every conceivable study have some forum, some printed herald to the world, and some mode of representation in council. Every active scientist feels the need of joining the groups with whose aims and ideas he is most in sympathy, and from whom he believes he can find the greatest incentive to his own progress; and, since the sciences have become diffused and intimately correlated, the societies which he feels almost compelled to join are both diverse and numerous. The tax upon him soon becomes onerous in consequence. The tax for loyalty in attendance, whether for performing duty or for mere encouragement of numbers, sometimes becomes as severe as the monetary tax for support. Then gradually comes a sensation of surfeit of journals, and meetings and congresses, and papers and reviews, until weariness and faintness ensue and a plaintive cry goes up that seems to indicate that the victim is perishing in the deep.

It must have been something unusual therefore in the conditions surrounding our profession which led so many of its devotees in this country, whilst impressed with the aforesaid dread of plethora of societies, to say nevertheless that they felt convinced, that in this case at least a new society was not only a desirable consummation not unduly burdensome, but was feasible, necessary and unavoidable. Still more: the entire body of adherents were impressed with the glory of the history of our other chemical societies and proud of their achievements. To the claim that these could do everything that could possibly be required to advance the interests of chemical engineering they paid due heed. Yet we find the demand still insistent for the formation of the independent new society.

There must be something deep and powerful at work in the minds of chemical engineers to cause this movement. There must be some force that will not down, some potency like the procreant spring which causes the signs of germination and the birth of being.

Let us examine the cause closely. At once we find that this will be an examination not only into the achievements of chemical engineering of to-day, but also into the duty to his nation and to mankind that lies before the chemical engineer of the future. Some will say that these are fine words, but that they mean nothing, or at least will lead to nothing. Can this be so when we who ought to know it best are convinced that chemical engineering is to-day, though unrecognized by the public, performing the greatest feats of economic salvation in the treatment of raw materials and in the production of staples and by-products?

Is it not true that the chemical engineer has oftener served the public than the public is aware of, and that he often stands ready to do so without a taker in the market of public life? The President of the United States calls together several hundred men, including statesmen, engineers and specialists of the most varied kinds and of the highest standing, to begin the study of the resources of our country, with a view to their conservation, amongst them forty or more society representatives and engineers. In the list it is a pleasure to see Dr. Dudley and Professor Bogart, Mr. Ingalls and Mr. Taylor, but elsewhere in the list, or even in the National Conservation Commission since appointed, there is not a chemical engineer or a chemist engaged in the treatment of raw material, yet the following are the words of our beloved President in forming the Commission:

"The work of the Commission should be conditioned upon keep-

ing ever in mind the great fact that the life of the Nation depends absolutely on the material resources, which have already made the Nation great. Our object is to conserve the foundations of our prosperity. We intend to use these resources; but to so use them as to conserve them. No effort should be made to limit the wise and proper development and application of these resources; every effort should be made to prevent destruction, to reduce waste, and to distribute the enjoyment of our natural wealth in such a way as to promote the greatest good of the greatest number for the longest time." This is almost a good definition of the work of chemical engineers, but they had no society to claim recognition as such.

The Mayor of a metropolis appoints a committee of experts to advise upon a new building code. There is not a chemist nor a chemical engineer amongst them.

The president of one of the largest chemical manufacturing companies in the world says in public that he would rather employ the engineer with a smattering of chemistry than the chemist with a smattering of engineering. Instances like this of either ignorance of the existence of a chemical engineer or of his capabilities or depreciation of his rightful place in the economy of affairs can be multiplied, very largely multiplied, I am very sorry to say.

Can this reference to the education of the chemical engineers of the future be idle words when we know that half of the waste of effort in so-called scientific work to-day is by reason of imperfect preparation of the scholar by which he confounds the means with the end, does not know what the best purpose of his own science is, and in the practice or the teaching of its applications follows a lowly aim with a restricted view? Whence springs the reproach heard against technical education, leading some to call our school laboratories boiler shops and some to call them brick yards, if it is not the narrowness of teaching which, in essaying to make useful men and call them scholars, spoils the scholars and dulls the useful men? Whence, too, springs the reproach to the chemical engineer himself that the public, which he knows he can aid, is not well enough acquainted with him to consider him worthy of being called in as an adviser of primary importance?

Those who have most closely studied the situation have stated that the chemical engineer must be better recognized, that his talents must be better appreciated and oftener used, that his opportunities must

be enlarged, his rewards increased, and, above all, his sons and oncoming successors must be better educated.

As to the recognition of the chemical engineer much of a pertinent character has been said during the discussions which we have so actively participated in during the last year. Mr. Stantial's comparison of the chemist to the cryptogamous plant was particularly happy and explanatory. In all times the alchemist, philosopher, chemist, analyst, have all been men of the study. A bold attack in the open and on a large scale upon some material in nature was never expected of them. The test tube seldom suggested the digester, the microscope is a teacher suggestive of nothing like itself, and as to text books one seldom thought of turning from them to utilize economic deductions from census reports. Thus an ideal and broad view of an industry demonstrating its importance, or the bold inventiveness of the genius who loves to do and dare, and is appalled by no obstacle, have meant nothing to the chemist of the closet; and the world took him at his own modest estimate. We have had, however, many glorious exceptions in history, men who, like Chevereul, have come down from the lecture table, gone into the factory and done the practical work so well, based on theory, that an entire change in an industry resulted. Or men like Castner, who could do and dare and invent and reinvent and face even the disappointment consequent on the destruction of an industry by some other invention at the moment of his own triumph in that industry.

The rule, however, being such, the inheritance has remained and chemists have been chemists, calling in the hydraulic engineer, the mechanical engineer or the practical man, as the field of work invited, just as they might call in the architect to design the arrangement of doors and windows in the halls in which they worked. Is it any wonder that the demand has come for a change and that the chemical engineer wants the world to know that with his deep-seated knowledge as a chemist of the reactions involved, and of the qualities of the raw materials, he has also engineering knowledge enough to design his constructions, make his own hydraulic calculations, and knows the qualities and strength of every material which would be put in place under his own eye, or has depth or ability to make economic and scientific studies whose results may be so far-reaching as to influence commerce and profoundly affect human activities. That the chemical engineer will oftener be consulted in the future is a certainty, if for no other reason than the fact that in modern times, and in very recent

years, we have seen some conspicuous demonstrations of the disasters caused by the failure to consult him or to yield to his teachings when large commercial undertakings were conceived and carried on in contravention of the warnings of science unheeded by the engineers, whose eyes were fixed only on the plan of construction. Mistakes in selection of site, in choice of raw material or fuel, in supply of water, in mechanical equipment or in treatment of material have been so numerous as would constitute almost an indictment of modern engineering if it were not seen that the fault in such cases is individual.

Economies in conveying or handling can be minimized or even destroyed in ultimate effect if great misconceptions of chemical principles have been allowed to remain uncorrected in furnace or tank or still. I must quote here some very apt and pertinent paragraphs of a private letter from Dr. H. Aug. Hunicke upon this subject. He writes:

"It is realized by those who are practicing chemical engineering that there is such an art. Each has, by years of experience, accumulated knowledge which he utilizes to advantage. Uncoördinated knowledge may be useful and often does perhaps form the bulk of what constitutes a practical art. Facts properly coördinated make science, and it is the process of coördination of already accumulated facts and newly discovered ones which must form the basis of the policy of a society of chemical engineers. A program so comprehensive should certainly justify the formation of a society such as is contemplated, and no better evidence is needed than the fact that it is at this time difficult to impress upon chemists, who have never been engaged in work requiring a knowledge of engineering, that there is a world of applied science still awaiting coördination to make it a tool in the education of the future generations. To-day only those who have been at some time engaged in the solution of problems presented by the industries with full power to assume responsibility of execution or administration, realize the needs, which in a measure it may perhaps still be difficult to formulate but which have impressed themselves upon the minds of those who are best fitted to judge the situation.

* * * * * * * *

"Such a section (he says, referring to the proposition of making a section and having an affiliation in an existing society) is in danger, by the preponderance of certain elements, of assuming a character entirely foreign to what it should be, and would doubtless result in

a mere duplication of already existing societies so far as the work is concerned.

"Without enlarging upon my ideas too extensively I wish to add that I am a little disappointed in observing that no speaker at the Hotel Belmont meeting alluded to a subject which brings out in a most forceful manner the specified differences of chemical engineering from all other forms of engineering. If we define engineering as the art of intelligently applying the forces and materials of nature to the needs of man, we will at once see the bearing of chemistry on one feature of engineering arts and realize at the same time that it is only the discoveries of the more recent years which resulted in the creation of a new science, that of physical chemistry, and which gave us the scientific principles to create that branch of engineering which has for its object the transformation of matter. In the past chemical changes were brought about by the strictest observance of conditions of operation, with the ever present dread that some, perhaps not recognized factor, had been overlooked and thus result in disaster. Modern science is, however, revealing laws which place us in a position to replace the old chemical instinct by clear conception, the direct outcome of our knowledge of the mechanism of chemical change resulting from the application of principles such as the law of mass action, velocity of reaction, equilibria, etc., which define the physical condition which must be fulfilled for the attainment of any desired end. This distinct characteristic of chemical engineering has until recently made it the more important that it should be recognized because it will in a large measure make it clear why chemical engineering has until recently been little more than mechanical engineering applied to the chemical industries; but that the day has come when chemical engineering has grown to be something distinct, a province of engineering differing from all others in that it aims at solving problems involving principles entirely foreign to the other engineering professions."

We can see therefore from these words of Dr. Hunicke how the problems that lie before the chemical engineer, and to the solving of which he brings all the new equipment which his own and other sciences have now placed at his disposal, make an array which is fascinating: Electrometallurgy, including what the electric furnace offers, catalysis applied as ingeniously to other reactions as to the oxidizing of sulphurous acid; synthesis, the use of the heat of oxidation of metals as a thermal process; nitrogen winning, and the host

of other problems which are in process of being solved or are already happily so.

Some have said that ours would be a society of "industrial chemists," and as you have several excellent societies already pledged and actively striving to do something for the "industrial chemist," a waste of effort is involved in our action here. But in that argument lies an error which needs only to be pointed out to bring conviction that we are now in the right position. This error is two-fold, and lies first in the misconception as to what constitutes chemical industry, and secondly, in the belief that outside of industry "the chemical engineer would have no field of action."

I would like to point out that Dr. Munroe, in his admirable report upon Chemicals and Allied Products for the Census of Manufactures, 1905, has specified as chemical industries the following twenty:

Sulphuric, nitric and mixed acids.
Other acids.
Sodas.
Potashes.
Alums.
Coal tar products.
Cyanides.
Wood distillation.
Fertilizers.
Bleaching materials.
Chemicals produced by the aid of electricity.
Dyestuffs.
Tanning materials.
Paints and varnishes.
Explosives.
Plastics.
Essential oils.
Compressed and liquefied gases.
Fine chemicals.
General chemicals.

He says that this must be arbitrarily done, for it is evident that every industry in which materials are used which can undergo a chemical change in process of manufacture, would have to be considered as a chemical industry.

Now here is a vast field for the chemical engineer not covered by

mere common acceptance of what is conveyed by the term *chemicals*. We would have the great industry of illuminating gas manufacture, coking and by-products; sugar manufacture; corn products; the silicate industries; detergents and a great array of textile, paper and leather industries.

Again, outside of these industries, we have the field into which the chemical engineer is now called of what might be termed water works chemical engineering. We have also the fields in which he is called when he becomes an adviser to a municipality, or to a railroad or to some great aggregation of manufacturers.

A minor plea for the justification of our Institute can be found in the hope of lessening the secrecy which invests most of the good creative work of our best chemical engineers in this country. It is difficult to estimate the proportion of this which is necessary, unavoidable and not unworthy; but as to what can be eliminated we are all agreed that "Let there be light" is a command which, if followed, will be for the good of all and the benefit of our country. I am reminded of a circular once sent out by a committee preparing for the annual meeting of one of our chemical societies at Buffalo. It stated that the committee had not been able to obtain permission to "visit chemical works or industrial establishments in Buffalo, but that the use of the city tug for a trip around the harbor had been obtained." Of course this is quite a number of years ago, and the liberality of the men at the head of the great works at Niagara has fully equalled the brilliancy of their inventiveness.

The best things ever said upon this subject as to secrecy in the arts have been stated by a brilliant and world-renowned American metallurgical engineer who began his career as a chemist, the great James Douglass, in his paper before the American Institute of Mining Engineers, Toronto meeting, 1907. Listen to him. He says:

"If it is the fact that technical science has progressed of late with such unwonted speed through the coöperation of many workers and that this coöperation has been made possible by the publication and exchange of ideas and experiences in the technical and scientific journals, would not our progress be even more rapid and thorough if all barriers of secrecy were broken down, and every encouragement were given to our technical workers to describe, in print and by conference, their notion and their actual experiments? This is the attitude of some, I may almost say of most, of our large concerns, but unfortunately it is not that of all. It is impossible to compare, as to efficiency

and profit, works the gates of which are fast shut, and in which obscurity and secrecy are imposed and practiced, with those to which free admission is granted and in which freedom of information is encouraged. But the following reflections force themselves upon us in this connection. We know that very few technical papers issue from certain establishments; that on their officials silence is imposed; and that to these works inquisitive visitors are politely but peremptorily refused admission. There are not many such, but they are and have been very successful. But suppose that in imitation of their practice and regulations all were tempted to adopt it, so that the same policy became universal; what a sudden paralysis of industry would follow! Our secretaries would find it difficult to fill even their shrunken volumes of transactions with papers worth printing; our students would have to content themselves with the antiquated learning which their professors could supply; for there would be no more summer classes for practical work in mines, smelters and electrical factories, and the professors themselves would have to learn from old books. Every manufacturer and smelter would be obliged to bribe his neighbor's workmen and tempt away his neighbor's superintendents for information. As a result, before long, the very works which now find it so profitable, or think they do, to tap their friends' stock of knowledge and experience, and give nothing in return would be driven in upon their own resources, and would undoubtedly then find them not so complete as they imagine. Of course, I am supposing an impossibility, because the spirit of the intellectual freedom in our professions is too strong and too widespread to submit to such tyranny, and because, before such darkness of ignorance had settled down on our great industries, the most pronounced advocates of secrecy would feel and acknowledge the ultimate consequences of concealment, and would become reformers. To-day they may have secrets, as valuable as Sir Henry's method of making plate glass and bronze powder, which it may pay them to conceal from their competitors, so long as they are admitted freely to their competitors' open shops; but even this is doubtful. For the spirit of secrecy is intimately allied with the spirit of suspicion and distrust; and the mind which is always suspecting is closed tight against the admission of fresh and fair impressions. Being jealous of others, it is prejudiced against their suggestions, and correspondingly prejudiced in favor of its own preconceptions. Progress therefore ceases.

"This is a temper of mind foreign to a new country like ours,

whose special industries have not been established long enough to wear grooves of rigid practice and sink into ruts of self-satisfied indifference. About the best correction we can apply to the growth of dry-rot is the banishment of secrecy. A curious instance of its blighting influence is seen in some of the older, not the newer industries of the old world. The iron and steel works of Europe have not kept pace with ours in size and production, but the iron masters of Great Britain and Germany, in coke-making and in blast-furnace economies and in steel-making processes, have been our teachers. Nor have they been shy of communicating their improvements, or, through jealousy of our success, slow in adopting ours. * * *

"I have supposed an extreme case—that the example set by our few secretive establishments were followed by all. Let me imagine a more probable issue, such as, I believe, will result from the fellowship of knowledge and experience which Mr. Carnegie, in presenting to our national engineering societies their new home, urges them to cultivate—namely, that all our technical manufacturers will learn how they gain, and not lose, by encouraging their staff officers to study their neighbors' methods, and by throwing open their own establishments, in turn, to the freest criticism of their competitors in trade. What will result? Nothing but advantage, I believe, to all whose wisdom and means have enabled them to provide themselves with the raw material to manufacture on advantageous terms, and to locate their works or factories at localities favorable for economical operation. Loss only to those who, in any case, ought to go out of business, because they have failed to secure the conditions essential to success! And above all, benefit to the public, which after all, is the finality we should always keep in view.

"How, now, can those two cardinal conditions—financial success and public approval—be best attained? Unquestionably, by mutual help and the most unreserved publicity. In any branch of industry, no intelligent worker claims he and his staff have attained either the utmost economy in operation or the most thorough acquaintance with all the reactions which enter the processes which he practices. Each knows that hundreds of other intelligent and well-informed men are eagerly at work on the solution of the same problem. Some may be a little cleverer than others, and some may have made a little more progress in certain lines than their co-workers. But this discrepancy will not necessarily continue; for the clever fellow is picked up by his rival works, the secret so carefully guarded leaks out, and the disturbed

average of paid ability and of stock of knowledge is restored. But if the companies and their staff are unwilling unreservedly to pool their knowledge and experience, the advantage of making into one great stock such accumulated experience and knowledge of these hundreds of workers is forfeited. With certain reservations, and by special permission, many of our large establishments, in all or in certain departments, are freely open to each other's technical officers; but instead of being admitted upon sufferance, they should be invited in with full liberty to study processes and test machinery; for assuredly the host would benefit as much as the guests by the discussion which would follow such unreserved exchange of ideas and comparisons of appliances and methods. * * *

"While unquestionably dangers can be foreseen as arising out of these great industrial aggregations—not only of capital but of industrial energy—dangers technical, social and political—there are also great possibilities of good. One of the benefits may justly be claimed to reside in the large funds that are thus rendered available for technical research, from which the public derives benefit indirectly even if the results are not published. But if we could banish secrecy; if every industrial establishment of any magnitude, which is in its own interest carrying on technical research, should encourage its technical staff to confer freely with the members of every other technical staff, would not sciences and arts progress far more rapidly than if one huge organization controlled a given industry? All our principal metallurgical and chemical concerns have laboratories, and carry on investigations and make experiments, generally on a large working scale; and surely the advancement of technological science can be better attained in a number of such laboratories than if there were fewer or in only one. There is keener competition of wits when many brains are working independently. The friction of honest rivalry is a force not to be despised. The stimulus of ambition is sure to be stronger in smaller than in large consolidated workshops. The air in such laboratories is freer and purer than when men are working in the stifling atmosphere of secrecy. I believe that such a consolidation of the mind and high impulses would carry us further and faster along the road of human progress than all the money that all the trusts could appropriate for the advancement of technical knowledge." * * *

But the noblest aim before us, gentlemen, the one which most amply justifies us before all the world, is our ambition for the enlightenment and ample equipment of our successors; that is for the im-

provement of the training of the chemical engineer of the future. How to design a course in chemistry and chemical engineering I leave to other times and other places; this is not the occasion to go deeply into that, the mere mention of which conjures up the greatest list of culture studies, sciences and arts to be mastered, and suggests the greatest variation of opinion among the masters themselves.

I would refer you to the papers of Guttman and of Nichols in the Journal of the Society of Chemical Industry, to the presidential address of Professor Richardson at the meeting last year of the American Association for the Advancement of Science, Section C, and to the address of Dr. Hunicke delivered before the American Chemical Society, St. Louis, a short while ago.

I will only ask for fair treatment for the student, and fair treatment for the young graduate who may not know that he has only just become a student of this practical science. I have often thought that the preceptorial system should be begun in our profession, that the advanced student should be favored with the friendship of a practitioner, and that advice should be given to him as to the utilization of his opportunities and the construction to be put upon his experiences. Encouragement should be given to judicious generalization and a little "shifting in his jobs" should be encouraged within reason. Frequent transplating, you know, is good for the root system of the young tree, but only an expert culturalist should oversee it.

While this society may probably have no junior grade, what it can and should do for juniors must be its first care. We need in the profession rather a few very deep scholars than a number of half-educated ones, or even a company of brilliant but superficial interpreters of science. A Muspratt, a Lunge, a Mont, a Nobel and a Castner are a larger asset for a country than a number of authors of specialized treatises giving minute details of some processes, many of which have disappeared from use. The mold of the mind is the important element in intellectual creation. Any other mold is but the mold of imitation.

I said in the opening that we begin as brothers. We inevitably will close our careers as fathers, passing on to our sons in the profession a heritage of knowledge and light that shall increase as the flame increases with the increase of fuel. No man who works for the success of this society works for himself. He can expect no reward other than the pleasure which comes from fostering a worthy cause close to his heart.

You who call yourselves Chemical Engineers, who know the science and the art, who feel your potency and your latent forces, you are to blame if you do not demand to be heard, to show by your efforts what stock you come from, and to demand of educators that in the future the title of Chemical Engineer be clear, the training adequate and the public encouragement the strongest.

Now all of these aims being noble, being peculiar to yourselves, enlisting your sympathies in a special way as they can those of the men of no other society, must we not conclude that the American Institute of Chemical Engineers has ample justification for existence, and will live, thrive and prosper?

CONSTITUTION

ARTICLE I.

NAME.

This organization shall be termed,

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

ARTICLE II.

OBJECTS.

The objects of this organization shall be:

To advance the cause of applied chemical science.

To give the profession of Chemical Engineers such standing before the community as will justify its recognition by Municipal, State, and National authorities in public works.

To raise the professional standard among Chemical Engineers, discouraging and prohibiting unprofessional conduct.

To coöperate with educational institutions for the improvement of the education of the men who are to enter this profession.

To encourage original work in chemical technology.

To promote pleasant acquaintance and social and professional intercourse among its members.

To publish and distribute such papers as shall add to classified knowledge in chemical engineering and shall increase industrial activity.

ARTICLE III.

MEMBERSHIP.

Section 1. (*Qualifications for Active Membership.*) Active membership shall consist of but one grade and shall require the following preparation and training:

All candidates must be not less than 30 years of age and must be proficient in chemistry and in some branch of engineering as applied to chemical problems, and must at the time of election be engaged actively in work involving the application of chemical principles to the arts. All candidates for admission to this Institute are expected to have *expert knowledge of at least one branch of applied chemistry.* and must fulfill one of the following requirements:

1. Candidates who hold no degree from an approved university or technical school must have had ten years' experience in chemical technology; five being in responsible charge of operations requiring the elaboration of raw materials, the design of machinery involving chemical processes, or the application of chemistry to industry.

2. Candidates who hold the degree of A. B. (Bachelor of Arts) from an approved university or technical school offering a four-year course must have had at least eight years of practical experience as outlined under No. 1.

3. Candidates who hold the degree of Ch. E. (Chemical Engineer), B. S. (Bachelor of Science), in Chemistry or Chemical Engineering, or E. E. (Electrical Engineer), C. E. (Civil Engineer), or M. E. (Mechanical Engineer), or equivalent degrees from an approved university or technical school offering at least a four-year course, must have had at least five years' practical experience as outlined under No. 1.

4. For candidates who in addition hold the degree of Ph. D. (Doctor of Philosophy) or Sc. D. (Doctor of Science) in Chemistry, the number of years required to earn the higher degree may be deducted from the number of years of experience required.

Section 2. (*Applications.*) All applications for membership must be made to the Secretary in writing, and shall embody a concise statement with dates of the candidate's professional training and experience, and shall be in a form and in such detail as may be prescribed by the Membership Committee. The applicant shall give the names of at least five members to whom he is personally known. Each of these shall be requested by the Secretary to certify to the training, experience, professional attainment, and standing of the applicant. On receiving a favorable report from at least three of these references, the applicant shall be eligible to recommendation by the Membership Committee.

Section 3. (*Election of Members.*) At stated periods the Secretary shall mail to the members a ballot containing a list of all applicants who have been recommended by the Membership Committee. This list shall contain a detailed statement of each applicant's career and the names of the members who have vouched for him. All ballots shall be returned to the Secretary not later than three weeks after the date of issue. The ballots shall be canvassed by the Membership Committee, who shall report to the Council, who shall then declare each applicant elected for whom at least ninety-five per cent. of all

ballots cast are in the affirmative. Provided, however, that any member voting in the negative may address a confidential letter to the Council, stating his objections to the candidate with evidence for the charges made. If the Council upon investigation considers such objections valid, they may declare an election void. A rejected candidate may make application again any time after one year. Persons elected to membership shall be notified at once by the Secretary. They must then subscribe to the rules of the Institute.

Section 4. (*Honorary Members.*) As the result of unusual ability and public recognition on the part of the industrial world, a person may, upon nomination of the Council and a vote of the Society at large, be made an Honorary Member, but at no time shall this number exceed five.

Section 5. (*Expulsions.*) For abuse or misuse of the privileges of the Institute or conduct unbecoming a member in the opinion of the Council, a two-thirds vote of the Council may expel any member of the Institute.

Section 6. (*Dues.*) The entrance fee shall be $15; Annual Dues $15. Provided, however, that no entrance fee shall be exacted until the membership shall reach 200.

Any member may anticipate his dues for life by paying in advance such a sum as would be demanded by any reputable insurance association to yield an annuity equal to the annual dues from the time of the agreement until death. Upon resignation, or expulsion, all money so provided is to become the property of the Institute. Any person joining the Institute after the middle of the fiscal year is required to pay one-half of the dues only for that year. Any person in arrears for three months shall be notified by the Secretary. For nonpayment at the expiration of one-half year, a member forfeits the right to vote or to receive the notices of the Association until dues are paid in full. All members are considered as such unless actual resignations are formally presented and accepted with the full payment of dues. On account of extenuating circumstances, dues may be remitted to any member by a two-thirds vote of the Council.

ARTICLE IV.

OFFICERS.

Section 1. The officers of this Society shall be a President, three Vice-Presidents, a Secretary, a Treasurer, an Auditor, and nine Directors. The officers shall be elected at the annual meeting. The President shall serve one year, the Vice-Presidents for three years each,

and the Directors for three years each. The Secretary, Treasurer, and Auditor shall be elected for terms of one year each. At the first annual meeting one Vice-President shall be chosen for one year, one for two years, and one for three years. Three Directors shall be chosen for one year, three for two years, and three for three years. Thereafter, officers shall be chosen annually to serve full terms. The President, Vice-Presidents, Secretary, Treasurer, and Directors shall constitute the Council of the Institute. The President, Vice-Presidents, and Directors cannot be re-elected within the current twelve months from the expiration of term. The duties of office begin immediately after election and notification. An acceptance of office must be in writing addressed to the Secretary. Vacancies occurring in any office shall be filled by a majority vote of the Council for the unexpired term. The duties of all officers shall be such as usually pertain to their offices or may be delegated to them by the Council or the Institute.

Section 2. (*Election of Officers.*) After the election at which this Constitution is adopted, the election of officers shall be by letter ballot. The Secretary, at least eight (8) weeks prior to each annual meeting, shall send to every member of the Institute a blank nominating ballot upon which the member may make nominations for the officers and Directors to be elected at the coming annual meeting. The nominating ballot is then to be properly signed and transmitted to the Secretary not later than five (5) weeks prior to the annual meeting. It shall then become the duty of the Secretary to prepare and issue an official ballot upon which shall appear the names of all nominations for office or for Directors which shall have appeared upon at least ten (10) nominating ballots. The official ballots shall be mailed not later than three (3) weeks prior to the annual meeting, one to each member, who shall properly signify on it his choice for the various offices and Directors, and transmit it to the Secretary. At the annual meeting the President shall appoint tellers to whom the Secretary shall deliver all the ballots received by him unopened, and who shall count and announce the vote.

ARTICLE V.

COUNCIL.

The Council shall have supervision and care of all property of the organization, and shall conduct its affairs according to the Constitution and By-Laws. At each annual meeting it shall present a statement of its proceedings during the year. Eight members of the

Council called together by notice from the Secretary shall constitute a quorum, provided, however, that three members may be represented by proxy.

ARTICLE VI.

STANDING COMMITTEES.

The Council shall appoint the following committees:

1. FINANCE.
2. COMMITTEE ON MEETINGS.
3. PUBLICATIONS.
4. MEMBERSHIP.
5. LIBRARY.
6 HOUSE COMMITTEE.

FINANCE COMMITTEE.

The Finance Committee shall have charge of the financial affairs of the Institute. This committee must prepare the budget and approve all expenditures. The Chairman of the Committee may be the Auditor of the Institute.

MEMBERSHIP COMMITTEE.

The Membership Committee shall be constituted of fifteen members, ten of whom may vote by proxy at any meeting. To the Membership Committee all applications for membership shall be referred. It is the duty of this committee to see that no person is admitted to the organization who is not qualified.

COMMITTEE ON MEETINGS.

This committee shall have charge of all meetings of the organization and shall fix dates and places of meeting.

COMMITTEE ON PUBLICATIONS.

This committee shall look after the papers presented to the Institute. If considered expedient, any or all of these papers may be published and distributed to members.

LIBRARY COMMITTEE.

This committee shall have charge of all permanent records, books, papers, pamphlets, etc., and shall obtain and place on file a complete record of all patent literature in reference to chemical engineering.

HOUSE COMMITTEE.

This committee shall look after the social affairs of the Institute, fixing the time and place of entertainments.

ARTICLE VII.

MEETINGS.

The annual meeting of the Association shall be held in December, the exact date to be fixed by the Council.

This Institute shall be governed by its Constitution in conformity with the laws of the United States. All questions shall be decided by majority of votes cast. The Institute shall not be held responsible for opinions expressed in papers. The name or use of the Institute shall not be tolerated for any commercial purpose.

Upon the adoption of this Constitution officers shall be elected immediately to hold office until the election and installation of their successors.

ARTICLE VIII.

AMENDMENTS TO THE CONSTITUTION.

Any member may propose an amendment by addressing the Secretary. At the first regular meeting thereafter the subject shall be discussed, and if worthy, notice to vote on same shall be posted until the next regular meeting, and written copy of the notice shall be sent to each member. The proposed amendment shall then be discussed in open meeting and can be passed by two-thirds vote of all members of the Institute as the result of letter ballot.

BY-LAWS

ORDER OF BUSINESS.

REGULAR MEETING.

Reading of minutes of last stated meeting.
Miscellaneous announcements.
Reading of papers, discussion, and communications.
Adjournment.

ANNUAL MEETING.

Reading of minutes of last stated meeting.
Miscellaneous announcements.
Stated business.
Annual reports.
Election of officers.
Address of retiring President, etc.
Adjournment.

In all questions requiring parliamentary ruling not provided for by the Rules of the Institute, "Robert's Rules of Order" shall be the governing authority.

FIRST ANNUAL MEETING

held at

PITTSBURG, PA.,

in the

CARNEGIE TECHNICAL SCHOOL,

December 28th and 29th, 1908

Monday Morning Session.

Dr. Arthur A. Hammerschlag, Director of the Carnegie Technical School, greeted the Institute with a welcome to Pittsburg and to the schools.

President Sadtler: "It is a matter of great pleasure to me that we were led to select this place for the first annual meeting of our organization, because Pittsburg is now pre-eminently a chemical center, and therefore I feel that we will all be satisfied that we were fortunate in choosing this place. I visited Pittsburg a good many years ago; I made my first business trip here in '75 in connection with the examination of natural gas for the Geological Survey. That was just at the beginning of the utilization of natural gas, which has made such a sweeping change in the aspect of things here in Pittsburg. Since then, this district has developed an enormous metallurgical industry, and you have also here in this part of the country the magnificent electrical industries of Westinghouse and others, as well as the oil and the steel industries and all the connected branches, so that I feel that we have made no mistake in coming to Pittsburg. I am particularly gratified, moreover, that we are welcomed in such a cordial manner by the Carnegie Technical Schools, because this is a typical example of the kind of institutions we would like to see developed in this country for the chemical engineering work which we are trying to represent.

Gentlemen of the Institute, we are now ready to begin our first annual meeting.

The following papers were then read and discussed:

"Technical Coal Analysis", by Dr. Edward Gudeman, of Chicago, Ill.

"Steam Power Plant Economics from the Standpoint of the Chemical Engineer," by Wm. M. Booth, of Syracuse, N. Y.

"The Chemical Aspect of Impurities, which Cause Scale and Corrosion of Steam Boilers," by J. C. William Greth, of Pittsburg, Pa.

"The Examination of Flue Gases in Boiler Tests," by Dr. H. August Hunicke, of St. Louis, Mo.

Monday Evening Session.

The following papers were read:

President's address, Dr. Samuel P. Sadtler, of Philadelphia, Pa.

"Heating of Industrial Furnaces with Pulverized Fuel," illustrated with lantern slides of the dryers, pulverizers and burners used. Richard K. Meade of Nazareth, Pa.

Tuesday Morning Session.

The following papers were read and discussed:

"Modern Electrical Resistance Pyrometry," by Dr. Edwin T. Northrup, of Philadelphia, Pa.

"An Apparatus for Testing Liquefied Ammonia Gas," illustrated with lantern slides, by Dr. F. W. Frerichs, of St. Louis, Mo.

Tuesday Evening Session.

"The Sanitary Condition of the Southern End of Lake Michigan," illustrated with lantern slides, by J. Herbert Brewster.

"Calculations for Dryer Design," by Dr. Wm. M. Grosvenor, of New York, N. Y.

The following papers were read by title only:

"Testing and Performance of Steam Generating Apparatus," by A. Bement, of Chicago, Ill.

"Chemical Specifications for Sulphite Pulp," by J. A. De Cew, of Montreal, Canada.

"Some Experiments with the Ferric Iron Contact Method of Making Sulphuric Acid from Smelter Fumes," by Thorn Smith, of Isabella, Tenn.

EXHIBIT OF CHEMICAL ENGINEERING APPARATUS

Automatic montejus, automatic eductors, lead-lined valves, syphons, heaters and spray nozzles. Schutte & Koerting, Philadelphia, Pa.

Chemical stone wares, exhaust "Goliath," plunger pump 1 liter capacity, Plath's reform acid pulsometer, centrifugal pump, cellarius vessels and others of similar description. Didier-March Co., New York, N. Y.

Temperature recorder in operation, dial indicator, dial indicator with differential galvanometer, deflection indicator, resistance thermometers, potential point thermometer. Leeds & Northrup Co., Philadelphia, Pa.

Welding and cutting of metals by oxyacetylene apparatus. Davis Bournonville Co.

Fuller Lehigh pulverizer mill. Fuller Engineering Co.

Lehigh Car Wheel and Axle Works. Fullerton, Pa.

Special acid metal valves, etc. Cleveland Bronze and Brass Works, Cleveland, Ohio.

Small model of round body evaporator. Zaremba Co., Chicago, Ill.

DRAWINGS AND PHOTOGRAPHS OF CHEMICAL APPARATUS AND INSTALLATIONS

Cement works, plans and layouts. Fuller Engineering Co., Fullerton, Pa.

Drawings of vacuum evaporators for various chemical work. Geo. M. Newhall Engineering Co., Philadelphia, Pa.

Drawing of electric furnace for the production of bisulphide of carbon. Edward R. Taylor, Penn Yan, N. Y.

Drawings of recently patented evaporators. Zaremba Co., Chicago, Ill.

DRAWINGS OF COMPLETE INSTALLATIONS

Nitric acid condensation apparatus, system Valentiner; nitric acid condensation apparatus, system Guttmann; hydrochloric acid plant condensing battery with cellarius vessels; denitrating plant, regeneration plant for nitrous gases, bromide plant, system Kubierschky; hydrochloric acid storing plant. Didier-March Co., New York, N. Y.

EXCURSIONS

The following plants were visited by members of the Institute:

Homestead and Duquesne plants of the Carnegie Steel Co.

By-product coke works of Carnegie Steel Co. at South Sharon, Pa.

Westinghouse Machine Co.

The Laboratories and Testing Departments of the Carnegie Technical Schools.

U. S. Government Explosives Testing Laboratory at Pittsburg.

BUSINESS SESSIONS

Monday, December 28, 1908.

During the morning session the minutes of the Philadelphia meeting were read and approved. The following committee was appointed to canvass the ballot for officers: Dr. Wm. M. Grosvenor, Henry Stanley Renaud and Dr. J. H. James.

Monday Evening, 7.30 P. M.

The Institute was called to order by President Sadtler. The committee appointed to canvass the ballot for officers for 1909 made the following report: Fifty ballots were cast and the following officers were unanimously elected:

President—Samuel P. Sadtler.

First Vice-President—Charles F. McKenna.

Second Vice-President—H. August Hunicke.

Third Vice-President—Edward G. Acheson.

Secretary—John C. Olsen.

Treasurer—Wm. M. Booth.

Auditor—Richard K. Meade.

Three Directors, elected to serve for three years—Ludwig Reuter, Thorn Smith, H. F. Brown.

TREASURER'S REPORT, DEC. 30, 1908.

RECEIPTS.

Contributions to defray expenses of Committee of Six—	
John C. Olsen	$10.00
F. G. Wiechmann	10.00
Chas. F. McKenna	32.90
Wm. M. Booth	38.00
	$90.90

TREASURER'S REPORT, DEC. 30, 1908—Continued.

RECEIPTS.

Membership dues, June 22 to Dec. 30—		
57 members, $7.50 each	$427.50	
1 member	15.00	
1 member	14.61	
1 member	7.00	
	$464.11	
Exchange	2.85	
	$461.26	
Total receipts		$552.16

ORGANIZATION EXPENSES.

Circular letter sent out by Committee of Six	$14.10	
Postage, printing and stenographer's services for Secretary of Committee of Six (Wm. M. Booth)	121.40	
Room, Hotel Belmont, for meeting of Committee of 50	10.00	
Stenographers' services for this meeting	43.75	
Printing minutes of this meeting	57.50	
Engineers' Club for Philadelphia meeting	10.00	
Stenographers' services for Philadelphia meeting	48.37	
	$305.12	

EXPENSES AFTER ORGANIZATION AT PHILADELPHIA, JUNE 22, 1908.

Printing: Stationery, envelopes, Constitution, application blanks, etc.	$111.31	
Expenses Secretary's office to Dec. 1	62.37	
Expenses Treasurer's office to Dec. 1	.80	
	$174.48	
Total expenses		$479.60
Cash on hand		72.56
		$552.16

WM. M. BOOTH.

REPORT OF MEMBERSHIP COMMITTEE

The Membership Committee of the American Institute of Chemical Engineers held sessions on July 15, August 12, September 2, October 20 and December 1.

At the session of August 12 a quorum was not present, and therefore official action could not be taken at that meeting.

The committee has taken action on a total of 101 applications; of these there were recommended for election to the Institute 88; action on 9 applications is still pending; and in 4 cases the committee decided that all of the requirements called for for admission had not been satisfactorily met, and therefore in these cases recommendation for membership was withheld.

The Membership Committee would like a discussion of and advice on a point which has come up several times in its discussions as to the exact construction of the age limit. That is to say, whether the 30 years' age limit prescribed in the constitution should be held to mean strictly 30 years of age, or whether it should be held to mean 30 years of age at the nearest birthday, a practice that is followed by the leading life insurance companies of the day.

The Membership Committee would like, furthermore, a discussion of and ruling on the question whether foreign applicants—by these being understood any and all applicants not residing in the United States, her territories or dependencies, or in Canada—should be eligible to membership in the Institute under the conditions as at present prescribed.

The Membership Committee would further suggest that in its opinion a suitable certificate of membership—size, style and wording to be hereafter determined—should be issued to all present members of the Institute, and should hereafter be issued to all who may be elected to membership.

The committee has informally considered the question of the adoption of a suitable pin, badge or other device, to be worn by members, and by members only, and in case this suggestion should meet with favorable consideration, would desire a ruling on the question as to whether the selection of such a pin, badge or other device should be undertaken by the Membership Committee, a sub-committee appointed therefrom, or some other committee specially appointed for the purpose.

Respectfully,

F. G. Wiechmann,

Chairman Membership Committee.

A motion to admit candidates to membership who are 29½ years of age was discussed, but not carried.

Upon motion, the preparation of a form of certificate of mem-

bership was referred to the Membership Committee, with instructions to report at the next general meeting of the Institute.

Upon motion, the adoption of a suitable pin or badge was deferred to the next annual meeting.

Upon motion of Dr. Gudeman, the question of fixing the time and place of the next meeting was referred to a committee consisting of the President, Secretary and one other member (Dr. Chas. F. McKenna appointed by the President).

On motion of Dr. Chas. F. McKenna, the Institute voted to appoint a Committee on Education, whose duties it should be to investigate the present condition of chemical engineering education in the United States and report at the next annual meeting.

Tuesday Morning, December 29.

Dr. H. August Hunicke, Chairman of the Committee on Publications, reported that the committee had decided to publish the first volume of Transactions. This volume would include a short history of the preliminary discussions which led up to the organization of the Institute at Philadelphia, also a complete report of the transactions of the Philadelphia and the Pittsburg meetings. The original papers read before the Institute, with the discussions, would be published in so far as they would be found suitable for this purpose, that is, would constitute valuable additions to the literature of chemical engineering.

The Committee on Publications also reported a resolution that: Members should be at liberty to publish papers read before the Institute elsewhere than in the Transactions of the Institute, provided that the following statement accompanies the paper: Read before the (Pittsburg) meeting of the American Institute of Chemical Engineers and presented in complete form for publication in the Transactions of the Institute. On motion, this resolution was adopted by the Institute.

At the evening session the Secretary was instructed to convey the thanks of the Institute to all those who had contributed to make the Pittsburg meeting successful, especially the local committee, Prof. James, Mr. Greth and Mr. Camp, as well as Dr. Hammerschlag, Dean Connelley and the officers of the Carnegie Technical Schools, who so courteously offered the use of their buildings to the Institute. Thanks were also rendered to the officers of the Testing Station, the Westinghouse Machine Co. and the Duquesne Steel Co., whose plants were

visited by members of the Institute, as well as the friends of the Institute who installed apparatus for exhibition to the chemical engineers present. Dr. Edwin T. Northrup and J. Herbert Brewster were thanked for preparing their papers for the Institute.

SOME THOUGHTS ON THE ORGANIZATION OF THE "AMERICAN INSTITUTE OF CHEMICAL ENGINEERS"

ADDRESS DELIVERED BY PRESIDENT SAMUEL P. SADTLER, MONDAY EVENING, DEC. 28, 1908.

The field of activity for a chemist in a country where many and diversified industries have grown up and developed until they involve the expenditure of many millions of capital has become wider and more complex than it was a generation ago. This widening of the field is reflected in the make up of our chemical society memberships.

Two decades or so ago, the membership of our American Chemical Society was made up almost exclusively of teachers of chemistry and analytical chemists, whether works-chemists or those connected with state and national stations as analysts. To-day it includes on its roll of membership a large additional number of chemists, who while interested in technical chemistry are more than analysts. They are men who, whether educated specially in the courses planned for the teaching of chemical engineering or not, have by choice or the force of circumstances been led to the study of the problems of chemical manufacturing, of chemical construction, and the applications of chemical principles and methods to the solution of industrial problems.

The same was true twenty-seven years ago in England when the English Chemical Society was somewhat similarly constituted, and when in the year 1881 the Society of Chemical Industry was founded to enlist the mutual coöperation of chemical manufacturers and to bring them together in meetings where the technical problems of chemistry would be the main topics of discussion. They proceeded to found on broad lines a society to cover this field and, largely by reason of its invaluable Journal, this Society has become international in its scope and now includes over 1,400 American members on its list, with a New York section, a New England section and a Canadian section, all holding monthly meetings for the presentation of papers and discussion of the same.

In England it will be remembered there existed at the time in addition to the English Chemical Society, the Institute of Chemistry and the Society of Public Analysts, and there has been organized since the

Faraday Society of Electro-chemists and Physical chemists, all of them at present in flourishing condition.

Similarly in Germany, we have besides the Deutsche Chemische Gesellschaft and of later date, the Verein Deutscher Chemiker with numerous local sections, the Bunsen Gesellschaft (or Electro-Chemical Society) and a number of flourishing chemical trade organizations, which publish journals and maintain scientific experiment stations.

In this country, the American Chemical Society has held together in a more successful way all kinds and styles of chemists, partly because of the existence here of three flourishing sections of the English Society of Chemical Industry, and partly because of the extensive organization of local sections of the American Chemical Society and the distribution of those attending the semi-annual meetings into an increasing number of sections for the presentation and discussion of papers. The only notable exception to this statement is found in the splitting away of the Electro-Chemists who some 7 years ago founded and have since maintained a flourishing society now numbering some 750 members.

But while we heartily rejoice that the American Chemical Society includes in its membership such a general representation of chemists of all kinds and tastes, there is another phase of the question that must not be overlooked.

While education or even more especially scientific education should be on broad lines, and while reading should not be too narrow, there are many problems and interests that for their consideration require a degree of concentration and specialization. Most of the great industries involving chemical applications that have been built up and placed upon a basis that makes their present working lucrative have achieved their success by the combined utilization of chemical knowledge, engineering skill, and good judgment in the application of both.

These great industries moreover are not stationary in the conditions of their practice. The same chemical knowledge, engineering skill and good judgment must continue to be applied as advances are made in the sciences, or they fall behind in the industrial competition.

There must therefore be a body of men supplied in increasing numbers who can take the technical charge of these industries, first as aides and ultimately as managers of the several works, qualified to continue the successful administration of the same and able to push them steadily to fuller development along safe and profitable lines.

Need I say that the young graduate of the ordinary college or

university course, with his training in the outlines of inorganic and organic chemistry and qualitative and quantitative analysis is not qualified to take up this work successfully. While he can analyze the purchased chemical supplies and make up standard reagents for the laboratory work, he is often of less value for the solution of the multitudinous factory or mill problems, upon which depends success or failure, than the young foreman, who has grown up from the ranks of unskilled labor, and who has no education but that acquired in the works. Are we then to depreciate a scientific education and the value of college training for young men? Not at all, but we must realize that the applications of chemistry in the modern industrial arts, other than the metallurgical industries, are wider and more far reaching than can be solved by the simple practice of the art of analytical chemistry, or application of the methods of chemical research learned in a University laboratory in connection with the writing of a thesis.

To be properly equipped for successful work in management and development of many industrial chemical processes, notably those utilizing organic materials, the chemist needs a more intimate acquaintance with the raw materials of the industry, whether fibres, cereals, gums, oils or resins and the physical and chemical properties that are distinctive in each case, than is commonly obtainable in a college course of instruction. This intimate acquaintance with the nature of the raw materials will open the door for the practice of proximate analysis as distinguished from ultimate analysis and here is a field for the acquirement of a fund of special knowledge, such as is rarely acquired by the young chemist in the ordinary analytical laboratory of the college or school.

Then a knowledge of the laws of physical chemistry as affecting solution, reactions and the reversibility of the same under varying conditions, crystallization and precipitation has become recognized as of supreme importance, as the bearing and application of these laws to practical manufacturing problems has been pointed out.

For the technical or factory chemist who desires to take responsible direction of the processes there carried out, a knowledge of the strength of materials and their behavior and adaptability under the conditions that prevail in the factory becomes also a matter of necessity.

Numerous applications of physical laws mainly in connection with the application or utilization of heat, such as the question of steam raising, condensation, and evaporation under normal and reduced pres-

sure, or in connection with the development and utilization of electricity in factory practice, are also elements for the training of the technical chemist of to-day.

While therefore good analysts are and will continue to be in demand, there is also a present and prospective need for what for want of a better title, we call "Chemical Engineers" to take responsible positions.

As I said before, many chemists who hold such positions at present have been led by force of circumstances to grapple with the problems of manufacturing and applied chemistry and have learned in the school of experience. Many younger men also are now coming into the field with something at least of the special education which fits them for this work.

So there is already a large body of men, scattered all over the country, who while members of a general chemical society like the American Chemical Society, or members of the English Society of Chemical Industry, for the sake of its invaluable journal, feel that they would like to come together in an organization to discuss the technical problems of industrial chemistry and the questions of engineering practice as applied in chemical construction or chemical operations. Outside of these, who are distinctively chemists, are others who are engineers connected with chemical works and industries, who are not members of any general chemical society but find here a common ground of interest.

The new institute will therefore include within its ranks at least four groups of men:

1. Industrial chemists and those connected with the management and technical direction of chemical works or factories.

2. Consulting chemists, who have had experience in planning and advising on chemical factory work.

3. Engineers, who have taken up and applied themselves practically to chemical problems.

4. Men, who without preparatory scientific education have by experience in chemical industries developed into responsible heads of manufacturing operations.

It is hardly possible, nor is it necessary to present here an account of the several meetings and discussions that preceded the organization of this institute, but mention may be made of one fact, viz., the general consensus of opinion of those who took part in these discussions that the new organization should not be merely a new chemical society,

open to all who were interested in applied chemistry, but the membership should be restricted as to experience, age and occupation, as was clearly brought out in many of the published letters. This view is embodied in the qualifications for membership (Article III, Sect. 1 of the constitution) which says "Active membership shall consist of but one grade and shall require the following preparation and training. All candidates must be not less than 30 years of age and must be proficient in chemistry and in some branch of engineering as applied to chemical problems, and must at the time of election be engaged actively in work involving the application of chemical principles to the arts. All candidates for admission to this institute are expected to have expert knowledge of at least one branch of applied chemistry, and must fulfill one of the following requirements," followed by the statement of allowances made for scientific degrees as against practical experience which it is not necessary to recapitulate.

It was felt and repeatedly expressed in the debates and letters of those who coöperated in the preparatory meetings that a society in which these elements of maturity and experience were considered as essential would be likely to exert more influence for good in the chemical profession than to start a new society for some special chemical field, with no special qualifications for membership.

With reference to the name, it seemed to the majority of those connected with this organization of the new institute that the name "American Institute of Chemical Engineers" had certain distinct advantages and justification for a body organized as this was. The title of engineer is no longer limited and used to designate a narrow profession, but is rather a term of broad application used by those who, with proper preparation and training, are occupied with the study of the problems of a wide range of industries. Following the original division, now a very broad one, into civil and mechanical engineers we have had the organization of mining engineers, electrical engineers, sanitary engineers, not to speak of hydraulic and marine engineers. Why should not those who devote themselves to the construction, development, and management of chemical manufacturing works take for themselves the name of Chemical Engineers? By establishing an age limit and strict standards of qualifications for admission, the title is dignified and not made cheap, as it might be if it were offered to anybody who had a desire for it, and joined the society so as to be able to use it. When the English Society of Chemical Industry was first organized in 1881, a number of its most active spirits were desirous of

choosing the name of Society of Chemical Engineers but it was pointed out that the term Society of Chemical Industry was a broader and more comprehensive term and, as the membership was not to be limited by age or experience requirements, the latter name was selected as more fitting. On the other hand the American Institute of Civil Engineers and several of the other similar national engineering organizations have strict standards of admission which operate to make membership in them a distinction. We believe that the same rule applied to an organization of those interested in the subject of Industrial Chemistry can be made to produce a similar result. As the designation "Member of the American Institute of Civil Engineers" following an author's name at the head of a printed paper or pamphlet, or on a letterhead is regarded as a certificate of qualification, so we believe will come to be the designation "Member of the American Institute of Chemical Engineers" in the near future. At all events, it is in our power to make it so, if we exert proper care in maintaining our standard of membership. We believe that the carrying out of the precautions detailed in section 3 of article III of our constitution by a vigilant committee on membership will go far toward insuring the desired result.

But what is there in our organization and its plans that commends it to those who are qualified and whose membership is desired?

The objects of the organization as stated in the constitution adopted last June are:

To advance the cause of applied chemical science.

To give the profession of Chemical Engineers such standing before the community as will justify its recognition by Municipal, State, and National authorities in public works.

To raise the professional standard among Chemical Engineers, discouraging and prohibiting unprofessional conduct.

To coöperate with educational institutions for the improvement of the education of the men who are to enter this profession.

To encourage original work in chemical technology.

To promote pleasant acquaintances and social and professional intercourse among its members.

To publish and distribute such papers as shall add to classified knowledge in chemical engineering and shall increase industrial activity.

While all of this is eminently praiseworthy, the point may be raised that members can hardly be expected to join a new organization and pay annual dues purely from altruistic motives and that they

may conclude that they can aid in attaining all desirable ends as well out of the organization as in it. Let us look at it therefore from this point of view and see what we have to offer to those whose coöperation we consider to be desirable, for, remember, we make no general appeal for members irrespective of qualifications.

The second of the objects of our organization as just enumerated is one which cannot but react advantageously to the individual member in the degree in which it is advanced. By aiding to give improved standing to the profession of Chemical Engineer, bringing it to the level of popular appreciation occupied by the members of the "American Institute of Civil Engineers" and the "American Society of Mechanical Engineers," we can justify the recognition of our membership by Municipal, State and National authorities in public works, when expert commissions are to be appointed. Many of the problems now before the municipalities as well as the various state authorities are preëminently such as the experienced Chemical Engineer is qualified to advise upon, much better qualified in fact than most Civil or Mechanical Engineers who have not devoted themselves to chemical questions. It is probably within the experience of most of us that we have been asked to help both civil and mechanical engineers, who have been called upon for solutions of problems of public interest but find themselves weak on the chemical questions involved. Why should we not strive to develop an organization from whose ranks experts could be taken when the occasion arises thoroughly competent to advise upon all questions of the applications of chemistry for useful purposes, the abating of nuisances by chemical agencies, or the utilization of natural resources by means involving chemical processes?

The third of the stated objects of the organization, viz., to raise the professional standard among Chemical Engineers, discouraging and prohibiting unprofessional conduct, is also a matter in which the individual has a personal interest. Membership in the American Institute of Civil Engineers now gives a guarantee of personal qualifications and standing which is of distinct value to those who hold it. We believe that the temptations to report in an encouraging way upon new and untried chemical inventions and projects to which a consulting chemist or chemical engineer is exposed are at least as great as those which confront a civil or mechanical engineer and hence the need of a concerted effort to uphold a strict professional standard. The reproach sometimes heard that an expert chemist's endorsement can be got by payment of a fee for any confidence game, involving a so-called chemi-

cal purification or production of improved product, ought to be wiped out, and will be if we will unite to do it by establishing and maintaining a high professional standard of conduct.

But it is the sixth and seventh of the stated objects that we believe will appeal most immediately to those who look into the question of cooperating in the establishment of this organization. The "promotion of pleasant acquaintances and social and professional intercourse among its members" is an element of value at all meetings of societies, but we know it is more generally realized in organizations of limited or selected membership as in certain clubs than in the meetings of large organizations. We believe that the special field of industrial chemistry will bring together men of common interests and yet be broad enough to furnish the diversity and newness of presentation that will attract our members and give them something to repay their coming together. We believe that both the social side and the professional side can be advantageously cultivated in such a gathering and we will be glad of the opportunity of meeting and exchanging views with many of our fellow members.

The seventh and last of the stated objects of the organization, viz., "to publish and distribute such papers as shall add to classified knowledge in chemical engineering and shall increase industrial activity" is surely one of the most important of the whole list of aims to be accomplished.

While there is no present plan to publish a journal or organ so-called we can undoubtedly and dare not neglect making the attempt "to add to classified knowledge in Chemical Engineering." This we can do first by gathering together the papers read at our annual meetings and the discussions on them into a volume of Proceedings, as is customary with the other Engineering Societies before referred to. These papers we may confidently expect at future meetings to embody more than was possible at this initial gathering of the results of more elaborate investigations upon new processes and products and with the accompanying discussions to form contributions to knowledge of the most valuable character, making our printed Proceedings indispensable to every technical library. Secondly, the institute can encourage the preparation of monographs or collective publications on selected topics of importance in Industrial Chemistry. There are numerous subjects of live interest to all chemical technologists that could be taken up in this way. For instance, a collection and classification of the most important publications from various journals on the contact-sul-

phuric acid process, beginning with the paper of Knietsch, presented to the German Chemical Society in 1901, and noting the most important patents and published discussions on this subject down to date, would make something that would be of value to all our members and would also be worthy of publication in the name of our institute. The same could be said of the still newer topic of such universal interest to chemists, viz: the fixation of atmospheric nitrogen, or the older but nevertheless important object of the by-product oven and its possibilities.

Thirdly, we believe that studies on subjects of technical importance could be encouraged by the establishment of prizes or medals to be awarded statedly by the institute. Many scientific and industrial organizations abroad have been made the custodians of funds established for the purpose of offering prizes. In some cases a series of problems are stated, upon which work is invited and the prizes are offered for the best paper upon these topics; in other cases the prize is awarded for what may be voted by the judges appointed to be the most valuable contribution published during a given interval.

There will undoubtedly be found many desirous of establishing such prize funds for the Institute of Chemical Engineers to administer as has been done in the case of similar organizations.

In conclusion we would say that if we all coöperate to carry out these plans and strive to realize the ideals that we have put before ourselves we cannot fail to achieve a success that will make us proud of the "Institute of Chemical Engineers" and abundantly repay us for any work which we have done as individuals.

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PAPERS

READ BEFORE THE INSTITUTE

STEAM POWER PLANT ECONOMIES

WILLIAM MILLER BOOTH.

Whether matter can be transformed into energy or into some other unknown state, future generations must determine. In the history of science we have found no startling exceptions to the assumption that matter and energy are constant throughout a long cycle of variations, provided we know how to test and measure phenomenal forms which these fundamentals may assume. The principles of steam power plant operation are a natural growth from such concepts.

But a fraction of the energy known to exist in coal can be turned to any useful effort in the production of mechanical power. Beginning with the crude boiler and engine of Watt's time, and following many changes with the addition of accessories in the way of artificial draft devices, improved methods of firing, and the later types of cut-off condensing engine, the economy has at least been multiplied by four. More recently the gas engine has in turn proved its place and the question before the engineers of the country is whether to discard the low efficiency steam power plant and steam engine in favor of the gas engine or to bring the efficiency of the former to a higher point than it has ever before been brought.

The operators of central electric power stations have at their command unusually favorable conditions for directly ascertaining the value of fuel. If one hundred tons of coal are burned per twenty-four hours and a certain number of kilowatt hours are produced, knowing the B. T. U. in the coal burned, it is not a difficult matter to determine the efficiency of the plant.

The purpose of a paper of this title is to bring out in a connected way the good and bad points of the power plant, particularly from the standpoint of expense of operation as found in the average mill or factory and also in the more perfect forms of modern power plant apparatus.

No meeting of mechanical engineers is held where power plant economics are not discussed to a considerable extent. Mechanical engineers must admit, however, that the problems of combustion

are chemical and that the chemist can render valuable assistance in connection with the burning of fuel and the utilization of its heating value. The combustion of coal, the purification of water and the control of flue gases are specifically chemical problems while the design of the boiler, the type of fire box and the physical parts of the plant are definitely engineering problems. The chemist and mechanical engineer must then meet on common ground. That this is possible we shall attempt to show in the course of the paper.

For years the handling of boiler plants was in the hands of practical but not highly educated men. Trained mechanical engineers have only had a chance to show their ability during the past ten or fifteen years. The losses have been found to be enormous. With fuel increasing in price and an increased use of power on every hand, too much attention cannot be given to this feature of National economy.

To show the actual increase in the use of steam power in the United States during 35 years, we call attention to the following figures which form a portion of a government report, Department of Commerce and Labor, Bulletin No. 88.

HORSE-POWER USED IN THE UNITED STATES.

1870.	1880.	1890.	1900.	1905.
2,346,142	3,410,837	5,546,655	10,409,625	14,641,544
		WATER POWER.		
1,130,431	1,225,379	1,255,206	1,454,229	1,647,969
		STEAM.		
1,215,711	2,185,458	4,581,595	3,140,533	10,828,111
		GAS ENGINE.		
.....	.....	8,930	134,742	289,514

It will now be of interest to derive the cost of a horse power year in a 24 hour plant of the better type, delivering 1,000 H.P. to the generator. That this cost might be made actual and not theoretical we have corresponded with boiler manufacturers, engine makers and power plant accessory concerns and from them have obtained bids for the cost of apparatus with its erection in Syracuse. Several different combinations can be made. The first one offered is as follows:

COST OF PLANT DELIVERING 1,000 HORSE-POWER.

*Three 252-H.P. B. & W. water tube boilers	$10,562.25
Erected and brought to a working standpoint	3,301.50
1,000-H.P. Harrison heater	600.00

*75% of bid for four boilers, similarly set.

Sturtevant economizer	5,000.00
Triplex Gould pump and electric drive	700.00
Steel stack, 72 inches by 125 feet	1,000.00
Stack accessories	400.00
Vertical cross-compound, McIntosh & Seymour engine	16,000.00
Freight, cartage and erection	1,800.00
Excavation and foundation	2,770.00
Condenser and pump	1,650.00
Erection and foundation hot well	150.00
Three superheaters	2,325.00
Piping	5,000.00
Pipe covering	1,000.00
Incidentals	5,000.00
Total	$57,258.75

FIXED CHARGES.

Interest on investment, 5 per cent	$2,862.93
Depreciation, 10 per cent. on value of apparatus	5,253.87
Taxes	572.58
Insurance, .005 per cent	286.29
Total	$8,975.67

COST OF OPERATION.

Coal $2.70 ton, running two boilers 8,760 hours per year, 2 pounds coal per H.P. hour,—cost coal	$23,652.00
Three engineers, $2.50,—8-hour day	2,737.50
Three firemen, $2.25,—8-hour day	2,463.75
Three helpers, $2.00,—8-hour day	2,191.00
Repairs	500.00
Oil, packing and waste, engine room included	800.00
Total	$32,344.25

It is assumed that the fireman's helpers remove ashes and deliver coal from cars.

ANNUAL COST 1,000 H.P.—EXCELLENT PRACTICE—HIGHLY ORGANIZED PLANT.

Depreciation, etc.	$8,975.67
Operation	32,344.25
Total	$41,319.92
COST PER H.P. YEAR, building not considered	$41.31

COST IN PLANTS ACTUALLY IN SERVICE.

900-H.P. electric plant	$140.00
2,900-H.P. electric plant	83.00
300-H.P. electric plant	230.00
4,000-H.P. electric plant, coal $2.40. Heine boilers, steam turbine, CO_2 recorder, superheaters, without depreciation	35.00

4,000-H.P. plant, coal $2.10, turbines, balanced draft, water tube boilers, including depreciation	75.00
1,000-H.P. plant, shell boilers, vertical high speed engines, poor electrical equipment with depreciation	307.00
If a Curtis steam turbine were used instead of an engine, the 1,000-H.P. outfit complete with condensers, set up for work, would cost about	$15,000.00

GAS ENGINE EQUIPMENT.

1,000-H.P. Allis-Chalmers engine and piping, complete	$42,000.00
One set Wyle gas producers	11,000.00
Piping	1,250.00
Incidentals	200.00
Total	$56,250.00

FIXED CHARGES.

Interest	$2,812.50
Depreciation	5,625.00
Taxes	562.50
Insurance	281.25
Total	$9,281.25

OPERATING COST.

Labor	$4,811.00
Oil, waste and supplies	1,990.00
Coal, $4.00 ton	15,642.00
Total	$22,443.00

DEPRECIATION AND OPERATION.

Depreciation	$9,281.25
Operation	$22,443.00
Total	$31,724.25
Cost per H.P. year	$31.72

Taking a 1,000 H.P. plant running condensing, 24 hours per day and assuming the price of coal to be $2.70 per ton, burning 8,760 tons of average (13,500 B. T. U.) coal, the actual fuel expense exclusive of labor would amount to $23,652. What work may be obtained from the coal thus burned is important to us as chemical engineers. The American Society of Mechanical Engineers has apportioned the various losses as follows:

HEAT LOSS, AMERICAN SOCIETY MECHANICAL ENGINEERS—1899.

Heat balance, or distribution of the heating value of the combustible; total heat value of 1 lb. of combustible.....B. T. U.

	B. T. U.	Per Cent.
1. Heat absorbed by the boiler = evaporation from and at 212° per pound of combustible × 965.7.		
2. Loss due to moisture in coal = per cent. of moisture referred to combustible ÷ 100 × (212° — t) + 966° + 0.48 (T — 212°). (t = temperature of air in the boiler room, T = that of the flue-gases)		
3. Loss due to moisture formed by the burning of hydrogen = per cent. of hydrogen in combustible ÷ 100 × 9 × (212° — t) + 966 + 0.48 (T — 212°)		
4. Loss due to heat carried away in the dry chimney gases equal weight of gas per pound of combustible × 0.24 × (T — t)		
5. Loss due to incomplete combustion of carbon $= \frac{CO \times \text{per cent. C in combustion}}{CO_2{}^* + CO \times 100} \times 10{,}150$		
6. Loss due to unconsumed hydrogen and hydrocarbons, to heating the moisture in the air, to radiation, and unaccounted for. (Some of these losses may be separately itemized if data are obtained from which they may be calculated)		
Totals		100.00

INTERPRETED BY KENT.

	Heat Units.	Per Cent. of Heat Value of the Coal.
20.67 lbs. dry gas × (560° — 60°) × sp. heat 0.24	2,480.4	17.41
.15 lb. vapor in air × (560° — 60°) × sp. heat .48	36.0	0.25
.029 lb. moisture in coal heated from 60° to 212°	4.4	0.03
.029 lb. evaporated from and at 212°; .029 × 966	28.0	0.20
.029 lb. steam heated from 212° to 560° .029 × 348 × .48	4.8	0.03
.405 lb. H_2O from H in coal × [152 + 966 × 348] × .48	284.99	2.08

*Equals percentage by volume in the flue gas.

.0237 lb. C burned to CO; loss by incomplete combustion, .0237 × (14,544 — 4,451)	239.2	1.68
.02 lb. coal lost in ashes; .02 × 14,544	290.9	2.04
Radiation and unaccounted for, by difference	624.0	4.31
	3,992.69	28.03
Utilized in making steam, equivalent evaporation 10.37 lbs. from and at 212° per lb. of coal	10,250.31	71.97
	14,243.0	100.00

FUEL LOSS IN DOLLARS FROM KENT'S TABLE.

Two pounds coal per H.P. hour, coal $2.70 ton, 8,760 hours per year, cost of coal		$23,652.000
Dry gas, 17.41 per cent	$4,117.813	
Vapor in air, .25 per cent	59.130	
Moisture in coal, 60° F., 212° F., steam to 560° F., .26 per cent	61.495	
Hydrogen in coal, 2.08 per cent	491.961	
Imperfect combustion, 1.68 per cent	397.353	
Fuel in ash, 2.04 per cent	482.500	
Radiation, 4.31 per cent	1,019.402	
Total	$6,629.654	
Useful effort, 71.97 per cent		$17,022.346

We believe that no more comprehensive outline for power plant economy has ever been tabulated than that by Mr. H. G. Stott in a paper read before the American Institute of Electrical Engineers, in Chicago, Jan. 26, 1906. We present this table.

LOSSES IN THE CONVERSION OF COAL INTO ELECTRICITY.

H. G. STOTT—1906.

			B. T. U.	%
1. B. T. U. per pound of coal supplied.	14,150	100%		
2. Loss in ashes	....	....	340	2.40
3. Loss in stack	....	....	3,212	22.70
4. Loss in boiler radiation and leakage	....	....	1,131	8.00
5. Returned by feed water heater	441	3.1	....	....
6. Returned by economizer	960	6.8	....	....
7. Loss pipe radiation	....	....	28	.20
8. Delivered to circulator	....	....	223	1.60
9. Delivered to feed pump	....	....	203	1.40
10. Loss in leakage and high pressure drips	....	....	152	1.10
11. Delivered to small auxiliaries	....	....	51	.4
12. Heating	....	....	31	.2

13. Loss engine friction	....	....	111	.8
14. Electrical losses	....	....	36	.3
15. Engine radiation losses	....	....	28	.2
16. Rejected to condenser	....	....	8,524	60.1
17. To house auxiliaries	....	....	29	.2
	15,551	109.9	....	99.6
	14,099	99.6	....	....
Delivered to bus bar	1,452	10.3		

When reduced to dollars in a 5,000 H.P. plant, with coal costing $2.70 ton, burning 2 pounds per H.P. hour the separate losses are as follows:

1. Coal used	$118.260.00	
2. Ash loss		$2,838.24
3. Stack loss		26,845.02
4. Boiler radiation and leakage		9,460.80
5. Returned by heater	$3,666.06	
6. Returned by economizer	8,041.68	
	$11,707.74	
7. Loss in pipe radiation		236.52
8. Circulator		1,892.16
9. Feed pump		1,655.64
10. Leakage and high pressure drips		1,300.86
11. Small auxiliaries		473.04
12. Heating		236.52
13. Engine friction		946.08
14. Engine radiation		236.52
15. Electrical losses		354.78
16. Rejected to condenser		71,074.20
17. House auxiliaries		236.52
99.6 per cent.	$117,786.90	

These losses are reckoned from a large, highly organized plant, running condensing. In a poorly managed plant running non-condensing the coal consumption is doubled and all losses are at least multiplied by two.

We will now take up separate causes of loss with suggestions for improvement.

Water.

This feature of the power plant should occasion but little trouble and yet it is a source of the greatest difficulty. Throughout the eastern and middle states hard, scale-forming water is prevalent and in the west alkali water occasions pitting and foaming. It has been very

common practice to locate a plant more particularly in reference to fuel economy or accessibility to a trunk line without attention to the water supply. Hundreds of plants have been erected in hard water regions and have suffered thousands of dollars' loss. Such loss may be completely remedied provided suitable study be given to the particular conditions present. Some waters should never be used for boiler purposes. We submit the analysis of a well water in the Mohawk valley. This well is 1,270 ft. deep.

COMBINED.	
Calcium carbonate	9.373
Calcium sulphate	.543
Calcium chloride	39.302
N_2O_5	.00
Magnesium carbonate	.930
Magnesium sulphate	.00
Magnesium chloride	32.333
Sodium chloride	293.350
Oxides of iron and aluminum	.542
Silica	.600
Total grains per U. S. gallon	376.973

This water is unfit for boiler purposes.

The best modern practice is to locate where there are two available sources of water, each entirely independent of the other. This is necessary not only in connection with the power plant but also as a protection against fire. Different combinations of river, lake, canal and city supply are used with a deep well as an auxiliary. If not in the salt belt, water from the latter is usually available for boiler purposes; if in this belt extending approximately from Canajoharie, N. Y., into Michigan, the gypsum, and the sodium and magnesium chlorides present may make the water useless for boiler purposes. In a deep well at Utica, N. Y., the sodium chloride amounts to nearly 300 grains per gallon; at Oneida, N. Y., to 30; at Syracuse to 500 or more; at Watkins, N. Y., to 30 grains.

We submit the analysis of a hard water.

GRAINS PER U. S. GALLON—PARTIAL ANALYSIS.

PARTIAL ANALYSIS.	Raw.	Tank.	Heater.	Boiler.
NaCl	.753	1.116	1.347	4.052
SO_4	53.274	48.011	48.771	200.110
CaO	34.637	2.754	1.877	8.643
MgO	4.869	3.894	3.261	.000
Alkalinity	8.60	8.59	8.77	6.00
Hardness	58.50	16.12	14.70	16.00

This water is highly charged with gypsum and is used in a 100 H.P. boiler located in a limestone quarry. Soda ash is added to the boiler supply in a large stone tank. Sedimentation results and the softened water is pumped into the heater. No trouble from foaming has been experienced at this plant which is handled by men entirely unfamiliar with the principles of water purification.

Having obtained a constant source of supply, surface boiler water should usually be filtered to remove suspended mud, sand and detritus.

The heater does not remove all carbonates as we have proved again and again. If water is treated in the boiler, predetermined mixtures of alkaline hydrates and carbonates usually satisfy the conditions. A 600 H.P. water tube boiler plant in Albany, is provided with 4 pounds of caustic soda per day at a cost of 10 cents. The daily cost in a 1,000 H.P. plant may amount with a water of 10 deg. hardness Clark to 25 or 30 cents. Frequent blowing of sludge is very necessary with such treatment.

If water of a hardness above 10 deg. Clark or if water below this degree of hardness scales boilers, we recommend a softening outfit of which there are now several efficient forms. The cost per H.P. amounts to about $3.00 for our typical plant of 1,000 H. P. The cost of operation will average 1½ cents per thousand gallons. We find returned water in use in many plants—usually from the hot well. This often contains oil. If present in quantity of 1 grain per gallon the water is usually clear and looks well, if 4 grains of oil are present per gallon the water is opalescent and the average engineer will not use it. The oil separator is simple, efficient and relatively inexpensive, yet we often find oil in boilers. This amounted in one instance to 40 per cent. of the sludge.

Mineral oil is not usually injurious to boilers if present in small quantity. Animal or vegetable oil mixtures *are very* dangerous when allowed to enter and remain in a boiler.

Much economy results from the use of heated, scale-free returned water. Steam turbine plants are running with a large percentage of such water. That danger may result we instance the experience in a modern 4,000 H.P. plant.

RETURNED WATER FROM TURBINES USED IN HEINE WATER TUBE BOILERS.

ZINC USED FOR SEVERAL WEEKS TO PREVENT SEVERE CORROSION.

ANALYSES.

	River.	Hot Well.	2 Weeks.	5 Weeks.	Scale.	
$CaCO_3$	8.362	5.116	4.093	6.140		
$CaSO_4$	5.678	10.935	7.777	77.543		
$MgCO_3$	.432	2.206	.000	.000	CaO,	31.50%
$MgSO_4$	4.444	2.631	.000	.000	MgO,	7.54%
NaCl	.867	1.300	2.438	20.397	Fe_2O_3,	8.00%
SiO_2	.748	.122	.064	.257	SiO_2,	4.59%
N_2O_5	.090	.087	.135	.212	Cl,	.10%
Fe_2O_3, Al_2O_3	.030	.099	.438	.666	SO_3,	1.42%
Org. and Vol.	5.599	2.474	4.629	23.815	Org.&Vol.,	46.95%
Na_2SO_4	.000	.000	3.923	3.450		
						100.00%

Severe pitting led to the use of slabs of zinc. These were rapidly corroded and destroyed, with considerable cost and without removing the difficulty. An analysis of the water and scale proved the corrosive action of some agent. Reference to the above table shows the most severe corrosion to have been co-existent with a high gypsum content and a high percentage of organic matter. Orders were given to blow the boiler 2 inches once in four hours. The difficulty then ceased. We add an analysis of raw and treated water as handled by the lime, soda ash process without heat.

REMOVAL OF SCALE.

	Raw.		Purified.
$CaCO_3$	9.415		1.643
$CaSO_4$	24.619		.000
$MgCO_3$	.000	$Mg(OH)_2$	1.160
$MgSO_4$	5.772		.000
$CaCl_2$	.000		.000
$MgCl_2$	.000		.000
Na_2SO_4	.000		25.705

By actual test in a 250 H.P. plant this apparatus has reduced the fuel bill 25 per cent.—a saving of $270.00 per year; also overcoming the annoyance of cleaning boilers which are opened once in three months instead of weekly.

Instead of closed heaters with consequent loss of soft water more recent practice takes advantage of an oil separator hot well, heater and pump. That large economy results provided the heater is in good condition is easily determined by the Stott table (page 58), where first-class conditions show a large profit above the cost of the heater in one

year's service. We find heaters giving very poor service in many plants owing to deposits of scale. In one instance a cleaned heater increased the temperature of the water of a 4,000 H.P. boiler plant 50 deg. F.—from 140 deg. F. to 190 deg. F. In another 1,000 H.P. plant the water passes through the heater practically cold. At this station much difficulty has been experienced with leaky boilers. A properly designed heater may increase the efficiency of a plant from 8 to 10 per cent.

Economizer.

To reduce the stack loss is a serious problem for the power plant specialist. Obviously the use of the heat in flue gases must result in large economy.

Economizers attempt to recover much of the loss. When, however, water is heated in an economizer at the expense of draft, the very basis of boiler economy is endangered. A fair figure for the cost of a 1,000 H.P. plant economizer would be $5.00 per H.P. This equipment is relatively expensive and must result in a large saving if used. If the temperature of the flue gases is reduced from 500 deg. F. to 250 deg. F., saving from 8 to 10 per cent. of the coal to useful effort, an economizer ought to be an excellent investment.

Whether the stack will survive is a question to us,—this time honored and simple method of creating a draft is enormously expensive, approximating 20 per cent. of all fuel burned in excellent plants and 50 per cent. in poorly managed plants. The chemist who is said to know no loss would expect to return the exhausted gases to the air at the same temperature as when taken. When this is done the boiler plant can be run much more economically. We are assured that the necessary draft for 1,000 H.P. plant can be furnished mechanically at an expense of 1 per cent. of the fuel burned and less if exhaust steam can be used to drive the fan.

Pumping water is expensive. Stott makes an estimate of 1.4 per cent. for a large plant, presumably with a rise against gravity of from 15-17 ft. and against a steam pressure of from 125 to 150 pounds. An estimate made by a pump manufacturing concern for a 1,000 H.P. plant is 1 per cent. or 10 H.P.—or at a cost of $400 to $600 per year. If water has to be lifted against gravity for a hundred feet or more the cost is appreciably greater than when city water flows into the boilers at a pressure of from 80 to 100 lbs. per sq. inch.

Condensers.

Enormous mechanical loss results from the use of steam

at low pressure. To condense one pound of steam quickly requires from 14 to 17 pounds of water which is heated without useful results. Some plants use double this amount. Thus it occurs that a 4,000 H.P. steam turbine plant is supplied by a 4-inch feed water pipe while the condensers are supplied with 12 inch mains. The water is heated and carried back to the forebay with a total loss of the heat contained. If high in temporary hardness, salt or organic matter it may prove difficult to keep the condensers clean; the vacuum is then much impaired. Could the condenser loss be obviated and the energy turned to mechanical advantage the steam power plant would take a new stand in the mechanical world.

Coal.

The price of steam coal is gradually increasing. While it may cost from forty to ninety cents to raise a ton of steam coal to the surface of the mine, freight rates are such as to make coal in St. Louis cost $1.00 to $1.30 per ton, in Chicago $1.50 to $2.00, while Syracuse manufacturers pay from $2.40 to $3.00; Watertown, N. Y., $3.00 and isolated cities in Massachusetts $4.00 to $5.00 per ton for coal. The "up state" manufacturers of New York are furnished a bituminous steam coal of about the following composition, costing about $2.70 per ton:

	Per Cent.
Moisture	1
Volatile matter	30
Ash	10
Fixed carbon	59
Total	100
Sulphur	2

Comparisons with Illinois coal shows the superiority of the Eastern supply. The moisture is negligable, the volatile matter is such as to give us fair results without stokers, while the ash is not unreasonably high. Very little consideration is shown concerns, especially small manufacturers, by the railroads;—as the shipments of one month may be excellent while the following month they may be poor. It is only the very largest purchasers that have any choice as to the quality furnished. The best arrangement is to make a contract with the dealer for a year's supply and to see that he maintains at least a medium standard. At the request of the superintendent of one of our large lighting companies we tested their coal for a period of about 2½

years. It was found that although the difference between two samples of coal might amount in price to thirty cents per ton, the difference in the efficiency at the distributing board might amount to one hundred dollars per day in the 4,000 H.P. plant.

In former papers we have discussed the subject of buying coal and believe that this commodity should be furnished upon a basis of available energy, so much per unit of heat, with draw-backs for high ash and sulphur. This method of purchase on the part of large corporations with first class engineering assistance is being rapidly adopted.

To ascertain the grate economy of several plants we made the following tests. The results were calculated by the following formula:

$$\frac{\frac{B}{100 - B}}{A} C$$

A = ash in coal.
B = comb. in ash.
C = per cent. original coal unburned.

UNBURNED COAL IN ASH OF FOUR PLANTS.

1. Machine Manufacturing Plant, 300-H.P. Modern Equipment—
   Ash in coal, 7 per cent.,
   Pardee coal,
   Heine boilers,
   Treadwell grates,
   Forced draft,
   Combustible material in ash, 16 per cent.
   Percentage coal not burned, 1.33 per cent.
2. Heating Plant, 2,100-H.P.
   Horizontal tubular boilers.
   Buffalo, Rochester and Pittsburg coal.
   Ash in coal, 10 per cent.
   Forced draft.
   Jones underfeed stokers.
   Combustible material in ash, 25.98 per cent.
   Percentage coal not burned, 4.60 per cent.
3. Paper Mill, 1,000-H.P.
   Water tube boilers B. & W.
   Neal shaking and dumping grates.
   Pardee coal.
   Natural draft.
   Ash in coal, 10 per cent.
   Combustible material in ash, 25.98 per cent.
   Percentage not burned, 3.50 per cent.

4. Paper Mill; New Equipment, 1,000-H.P.
Horizontal tubular boilers.
Standard stokers.
Ash in coal, 10 per cent.
Combustible material in ash, 36 per cent.
Coal not burned, 5.62 per cent.

There is unquestionably an average fuel loss in ash that the power plant owner might consider with profit.

Boiler Tests.

It has been the custom to test boiler efficiencies by evaporative tests. This seems to be a perfectly logical method. Of late grave doubt has been expressed of the efficiency of such a test. If all boilers were similarly set, fired by the same man, provided with similar grates and draft, and if the same grade of coal were used, comparisons might be drawn, but these elements vary so materially that successive tests of the same boiler by different men may show widely differing results. The explanation may at times be difficult to offer, but the quantity of air supply, the direction of the wind, if natural draft is used, the humidity of the air, the size of the grate and the personality of the fireman all contribute to the final result.

Although the laws of combustion are very thoroughly understood by scientific men very little attention is paid to them by firemen or those in charge of power plants. With insufficient draft, a poor setting and bad firing, boiler efficiency may reach its minimum. We have in mind a thousand H.P. shell boiler plant furnishing electricity to light a town of ten thousand people. This plant was built on a very imperfect foundation with piles under the walls and the main machines only. The boilers have settled six inches toward the front. The water contains scale-forming ingredients to the extent of about 30 grains per gallon. The stack is 50 ft. too short, the engines pound, the dynamos are out of date, and other difficulties have arisen so that the cost of producing a K.W. hour is between four and five cents. On the other hand, a 4,000 H.P. plant of modern construction with "Balanced Draft" and a mixture of hard and soft coal is furnishing electricity for slightly more than one cent per K.W. hour. A four thousand horse power plant, also electrical, provided with water tube boilers and a steam turbine, with a CO_2 recorder running about 12 per cent. CO_2 is furnishing power, not including depreciation, for one half cent per K.W. hour.

Not because he has wished to do so, but because the public has

demanded it, has the power plant owner been compelled to burn fuel more economically on account of smoke ordinances. The design and location of the fire box are important factors. The perfect fire box has yet to be constructed, but the general tendency seems to be an increase in the height of the boiler above the fire and the use of incandescent walls to burn hydrocarbons. It is at this point that the chemical engineer becomes an interested party.

It is our experience that stokers have no superior advantage to hand firing with eastern coals, besides they render the plant less flexible to change in load. The ash loss is usually much greater with stokers.

We wish now to discuss more particularly the use of apparatus for testing flue gases with the results obtained, and further to show the efficiency of such apparatus.

The general tendency in firing a boiler is to get a pronounced draft if possible, and to drag an enormous quantity of air over the fire. This air is heated without useful results. We had the opportunity of investigating the conditions in reference to firing and flue gas analysis at a heating plant running 24 hours per day continuously from fall until spring. This plant consists of 3 300 H.P. horizontal tubular boilers; 9 125 H.P. boilers; similarly set and fired. These are furnished with Jones underfeed stokers. Each stack runs about 50 ft. above the breeching and serves two boilers. The draft is forced by a 10 ft. fan run at 180 to 250 revolutions per minute. To measure the degree of combustion an Orsat apparatus was purchased. In the breeching of each boiler a perforated pipe was placed. These were connected throughout the entire length of the plant, which is probably 150 ft., and each boiler was provided with a tight closing valve. At the end of the line and upon a small platform an aspirator was arranged with suitable water supply. This was connected with the pipe line through a gallon glass bottle with a heavy rubber three perforated stopper. The gas before entering the bottle passed through a cooling coil made from half inch gas pipe with about six turns. The water from the aspirator cooled the coil. The third glass tube was connected with the Orsat apparatus. The first test was made with the air of the fire room which was very sulphurous and close. This analysis was as follows:

CO_2	2.8 per cent.
Oxygen	17.0 per cent.
CO	.20 per cent.

With forced draft it is not difficult to understand why we obtained such an analysis. Although no further test was made of the air in the boiler room we often found it very bad. Tests were begun on the 12th day of February, when it was found that the carbon dioxide was running between 2.8 and 3 per cent. The manager of the plant, a good engineer, spent the next two weeks in tightening up his boiler settings. Under some boilers these settings were found to be very deficient with large cracks. On the 16th day of March tests were begun and were made by the firemen, the engineer in charge and myself. Before May 5th, 1,275 tests had been made. The engineer and I made complete tests for CO_2, O_2 and carbon monoxide but could not find more than .2 per cent. carbon monoxide and usually none. The firemen would not take the trouble to follow the CO test as they were less sure of this than either of the first two. Rather than disliking this matter they spent a great deal of time trying to make their firing more efficient, and a great deal of interest was evinced when the tests proved equal to or better than 15 per cent. As an example of the number of tests run during the day on single boilers the following table is appended:

CARBON DIOXIDE TESTS, BOILERS' HEATING PLANT.
TESTS FOR DAY.
No. 14.

Time.	Fan.	Carbon Dioxide. Per Cent.	Oxygen. Per Cent.	Fire.
1.30 A.M.	230	14.2	5.0	Heavy
4.00 A.M.	230	14.2	4.8	Heavy
7.00 A.M.	230	14.2	2.8	Heavy
8.45 A.M.	230	16.4	.6	Heavy
10.30 A.M.	230	15.0	3.0	Heavy
12.30 P.M.	230	15.0	3.0	Heavy
1.15 P.M.	230	16.2	.8	Heavy
2.30 P.M.	230	16.4	2.2	Medium
3.00 P.M.	230	15.0	4.0	Medium
4.30 P.M.	230	15.8	1.6	Medium
7.45 P.M.	230	16.8	2.8	Medium
9.45 P.M.	230	15.0	3.2	Heavy
11.45 P.M.	230	14.8	2.8	Heavy

No. 15.

Time.	Fan.	Carbon Dioxide. Per Cent.	Oxygen. Per Cent.	Fire.
4.00 A.M.	230	14.6	3.6	Medium
8.30 A.M.	230	15.0	1.0	Heavy
9.00 A.M.	230	16.0	.4	Heavy
11.15 A.M.	230	16.0	2.4	Heavy
1.00 P.M.	230	16.0	.6	Heavy
2.00 P.M.	230	17.4	.6	Heavy
2.45 P.M.	230	17.0	2.2	Heavy
7.30 P.M.	230	17.0	1.0	Heavy
9.30 P.M.	230	15.8	2.2	Heavy
12.00 P.M.	230	15.0	3.0	Heavy

With every precaution we were sometimes unable to get an oxygen and CO_2 percentage of more than 16 total.

Boilers Nos. 14 and 15 were nearest the apparatus and had been very hard to get good results from, while boiler No. 6 was well toward the end of the plant and was of much less interest to the firemen. Chart No. 2 shows the increase in percentage of carbon dioxide during the period mentioned. The temperature in the breeching was about 500 deg. F. at the outset. At times it rose to 600 deg. F., but seldom above. Consulting a CO_2 economy table we can allow an increased efficiency due to knowledge of and care for flue gas conditions of at least 30 per cent. of the fuel or a saving of $70 per 24 hours.

TESTS MADE IN OTHER PLANTS.

A PAPER MILL, 1,000-H.P. BOILERS.

TESTS MADE ON BOILERS, WEDNESDAY, DEC 16, 1908.

ROOT BOILER.

	Carbon Dioxide.	Oxygen.	Carbon Monoxide.
First test	3.40%	17.40%	.20%
Second test	4.00	15.60	.40
Third test	3.60	16.60	.20
Average	3.66	16.53	.26

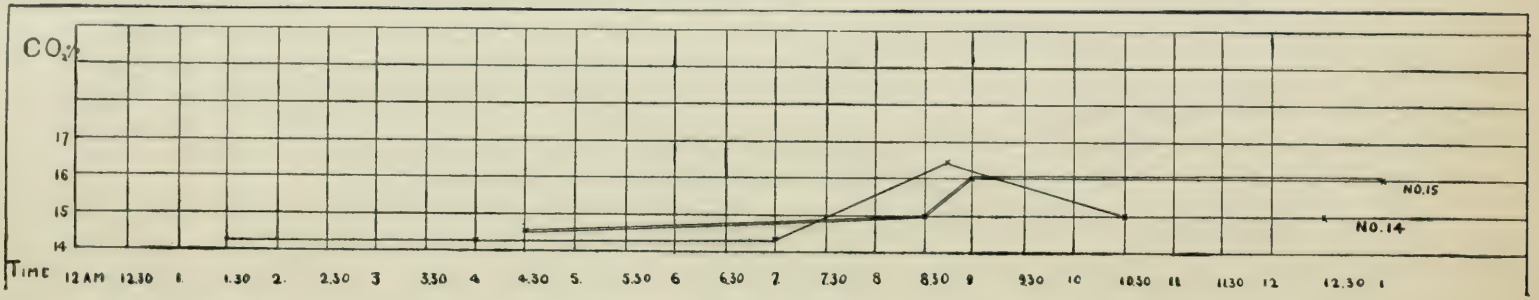
Stack temperature, 383° F.

Draft in breeching, 3/16 inch.

(NO. A) B. & W.

	Carbon Dioxide.	Oxygen.	Carbon Monoxide.
First test	2.60%	17.20%	.00%
Second test	7.20	18.20	.00

Chart No. 1.



The results given in the preceding tables, tests Nos. 14 and 15 are shown graphically by means of these curves.

Third test	5.40	13.80	.00
Fourth test	4.20	.....	...
Average	4.85	14.40	.00

Stack temperature, 410° F.
Draft in breeching, 7/32 inch.

(NO. B.) B. & W.

	Carbon Dioxide.	Oxygen.	Carbon Monoxide.
First test	3.44	17.00	.20
Second test	3.60	16.60	.00
Average	3.52	16.80	.10

Stack temperature, 455° F.
Draft in breeching, 4/16 inch.

The fuel loss on all three boilers due to excessive air amounts to a quarter of the coal burned.

MODERN POWER PLANT.

TWO 150-H.P. HEINE BOILERS; TREADWELL GRATES; STURTEVANT FAN; FORCED DRAFT. THESE BOILERS ARE SET EXACTLY ALIKE AND ARE CONNECTED WITH THE SAME STACK.

DEC. 15, 4 P. M.

	Carbon Dioxide.	Oxygen.	Carbon Monoxide.
No. 1 boiler	11.2%	8.00%	.00%
No. 2 boiler	8.4	12.00	.00
No. 1 boiler	15.8	3.60	.00
No. 2 boiler	7.6	11.60	.00
No. 1 boiler	10.4	9.60	.00
No. 2 boiler	11.4	7.40	.00

We consider the results on No. 1 excellent.

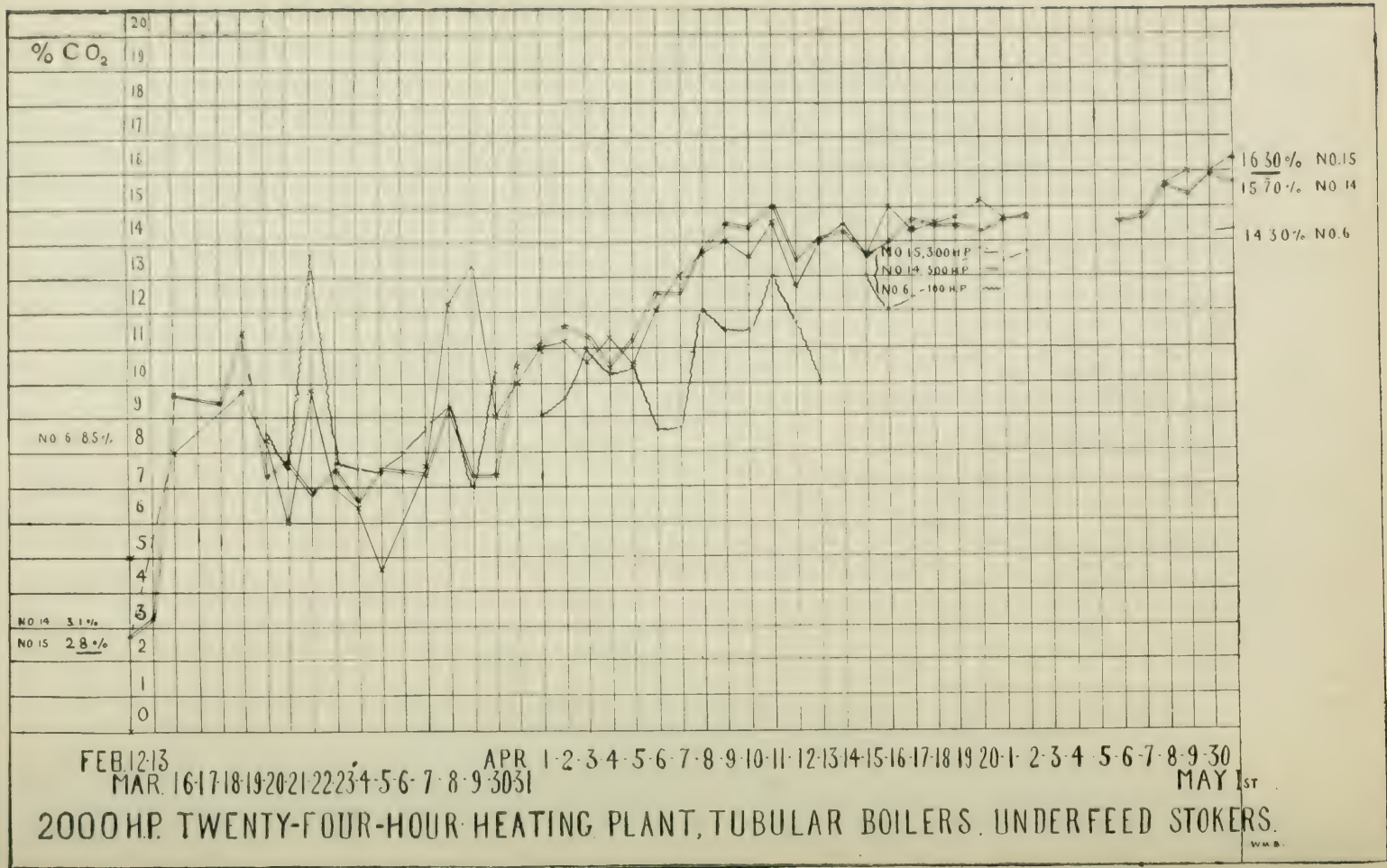
DEC. 23, 11 A. M.

	Carbon Dioxide.	Oxygen.	Carbon Monoxide.
No. 1 boiler	11.8	7.80	.00
No. 2 boiler	8.6	11.40	.00
No. 1 boiler	13.2	5.80	.00

SUMMARY.

In the course of this paper we have shown that a highly organized electric plant is capable of delivering 10 per cent. of the energy of coal as useful mechanical work. With the latest type of apparatus includ-

Chart No. 2.


% CO2
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
NO 6 8.5 %
NO 14 3.1 %
NO 15 2.8 %
NO 15, 300 H.P
NO 14 500 H.P
NO 6 - 160 H.P
16.30 % NO.15
15.70 % NO 14
14.30 % NO.6
FEB. 12-13
MAR. 16-17-18-19-20-21-22-23-4-5-6-7-8-9-30-31
APR 1-2-3-4-5-6-7-8-9-10-11-12-13-14-15-16-17-18-19-20-1-2-3-4-5-6-7-8-9-30
MAY 1ST
2000 H.P. TWENTY-FOUR-HOUR HEATING PLANT, TUBULAR BOILERS. UNDERFEED STOKERS.
W.M.B.

ing water tube boilers, superheaters and steam turbines the efficiency has been raised to 15 per cent. Surely a remarkable gain over the 6 or 8 per cent. of a few years ago or the 3 or 4 per cent. of fifty years ago! Four pounds of coal per H.P. hour is good practice, but the best condensing engine or steam turbine reduces this coal consumption nearly 50 per cent. With a gas engine and gas producers one H.P. hour can be produced with one and a quarter pounds of coal producing an efficiency of about 22 to 25 per cent. No steam or gas apparatus can compete with water power with an efficiency of from 87 to 92 per cent. of the total energy of the falling water. If conveyed to a distance electrically the loss may reach 40 per cent. total. Fixed charges are, however, very heavy in large installations. A good boiler delivers 70 per cent. of the heat of the coal, the average boiler not more than 50 per cent. with the enormous condenser loss of the engine. The use of the boiler in chemical plants and wherever steam is required will probably never lessen, nor is this an inefficient apparatus for the purposes intended.

The use of the gas engine exhaust for practical purposes, especially heating, will do much to bring this form of power into favor. The present cost of the large unit gas engine and the uncertainty of its operation are factors being rapidly overcome.

Undoubtedly the steam plant will continue for many years on a constantly increased scale as large installations result in greater economy.

That the plant may be made the most efficient, expert power plant engineers must be employed. The plant must be *designed* by the most experienced and *operated* under the guidance of educated men,—engineers, firemen and helpers,—25 per cent. of the cost for fuel is a conservative estimate of the saving possible.

The CO_2 recorder and recording pyrometer should be provided in every plant of 1,000 H.P. or above, the Orsat apparatus should be used in all plants above 250 H.P., the coal should be tested, the ash tested as well as the water *from* the boilers. Firemen should be paid in proportion to their results. Coal and ashes should be handled mechanically. If the plant is built fireproof the insurance rate may be below 25 cents per $100,—if not it may rise to $7.00.

That present conditions in power pants must be much improved is evident after considerations such as we have followed. The field is broad and the call urgent.

Approximate Cost Per H.P.

APPARATUS THAT MAY BE USED IN 1,000 H.P. PLANT, CONDENSING.

Boilers	$10.56
Setting	3.30
Condensing engine	20.57
Condensers	1.65
Softener and filter	3.00
Heater	1.00
Stack	1.00—$6.00
Pump	1.00
Piping	6.00
Balanced draft	3.50— 5.00
Induced draft	1.00
Superheaters, Foster	.75
Stokers	5.00
Economizers	5.00

(Discussion) Dr. Gudeman: "How does Eastern coal compare with our Illinois soft coal?"

Mr. Booth: "They are not alike."

Dr. Gudeman: "Twelve per cent. carbonic acid would be low for a well operated plant on the Illinois coal."

Mr. Booth: "With 10 per cent. water in the coal?"

Dr. Gudeman: "That would bring it up to about 13¼ per cent. on a dry basis. We have many plants in and around Chicago where we have no smoke to contend with. At the plant you were referring to, The Edison plant, you do not see a bit of smoke."

"The last I heard of the Edison plant it was running at 16 per cent. CO_2."

"If with Illinois coal the CO_2 goes down below 5 per cent. the fire will go out. It is pretty hard to keep up a fire with less than 5 per cent. if the coal is very soft."

Dr. McKenna: "I would like to ask Mr. Booth in regard to the corrosive condition of the turbine plant water."

Dr. James: "The magnesium sulphate would account for the corrosion in that water."

Mr. Booth: "You understand, Dr. McKenna, that that was a revelation to the people in that plant; they thought they must be drawing acid from the river, but they were running the water in a circle and each time adding a little hard water for losses and it resulted in a very bad combination. I told them that the engineer could get along by blowing the boilers often, he obviated the difficulty

by blowing the boilers every two hours at first and then every four hours. That is the key note of my experience, blowing off of the boilers and getting out the alkali and sludge, then the water will take care of itself. The engineer is afraid of losing heat in this way."

MR. GRISWOLD: "I was interested in the remark made about the firemen in making the CO_2 records. I inquire because we have tried it in making our CO_2 records. We had to take care of six boilers at once and almost took care of the firing of nine at one time. We have raised our record from 7 per cent. to 12 per cent. We took the handles off the dampers and threw them away or put them where they could not be used. We cut 20 feet off the top of most of our steel stacks and put inside 2" of cement lining, yet we had sufficient draft and cut down our coal bill considerably. It looked to be about 10 per cent. We have relatively large coal bills—Michigan coal is very high in ash. They use mechanical stokers mostly. I would like to have a few give their experience on the premium plan."

MR. BOOTH: "In reference to heating plant: The firemen were very rapidly getting better results. There must have been 12 or 14 men in that plant. They vie with one another in getting results. My plan in reference to a premium is that we should have a fireman who knows what he is doing, he should have some kind of an education. Just what premium will be paid, time will probably work out. In our own case the fireman will either do as we say or he will have to go. Maybe some of the men here have this plan in operation now."

DR. GUDEMAN: "Mr. Chairman: In reference to the remark that the boiler efficiency in Europe is a great deal higher than it is here,—that, in my estimation is due to the firemen. In this country, they require a license for an engineer to run an engine, and if you should look up the statistics of explosions, in the plants run by steam engineers you would find the percentage very small compared with that of our boiler explosions. I know of no place where a fireman must be more careful than in taking care of a boiler furnace. I agree with the remark that a good fireman can generally bring up the efficiency of the plant very high."

MEMBER: "There is one point which Mr. Booth mentioned regarding the increased efficiency, stating that the boiler men have not raised the boiler efficiency otherwise than by putting in the fire walls, then the firemen have to alter the boiler and all this is simply to get a large surface which will enable the gases to have an unobstructed surface; that is very important. There is no proportion between the

diameter of the combustion chamber and the fuel that is to be burned. They (the manufacturers) say it ought to be so and so, then the boiler does not do the work, then they say, 'Well now, we will have to alter that;' they will do anything to obstruct the gases going through. It is very necessary that all these gases be united after coming through. You have got the gases but you have not got the space in which they are to burn."

DR. GUDEMAN: "In a 20,000 H.P. plant in Iowa, conditions are met, with which no comparison can be found in Eastern plants. The ash in that coal runs anywhere from 35 to 45 per cent. The evaporating efficiency there was, I think, 4 lbs. of water per pound of coal. By increasing the combustion chambers and building Dutch ovens, we brought the evaporation up to 6½ pounds. It is safer to run the oven outside the boiler. But there I think is the greatest defect in boiler construction—that the combustion chamber is not in proportion to the fire chamber—the coal has not room enough in which to be burned. They try to overcome that by putting the gases through at an increased speed."

MR. BOOTH: "Are the stokers doing well with you in Chicago?"

DR. GUDEMAN: "There are plants getting splendid results from stokers. I have seen them using four different kinds of stokers and hand firing in the same plant and I could not find that it made any difference. It is simply in the operation. If you are getting a uniform coal you can make your stokers work very nicely. There is an advantage in using stokers in Chicago at boiler work—it takes a man with more knowledge of machinery and therefore you get better firemen."

PRESIDENT SADTLER: "I would like to have this matter discussed at greater length but we will have to go on with our next paper."

TESTING AND PERFORMANCE OF STEAM GENERATING APPARATUS

By

A. BEMENT

As an early invention, the steam engine received special attention because it directly performed work, while the apparatus which supplied the steam was considered rather of secondary importance, being devised to furnish the steam required by the engine. Inasmuch as steam was produced from water by boiling, the apparatus was called a boiler, and by ordinary definition and common practice, a boiler has come to be considered a metallic structure which contains the water. Thus an exact definition of the word boiler excludes fire bars, brick containing walls, chimney and the various appurtenances required in the effective employment of a boiler. That such is the case is evidenced by the fact that many manufacturers of boilers build only this metallic structure. They contract to construct and supply what are designated as boilers and receive payment therefor, although they provide for none of the appurtenances above mentioned. Again, many others are in the business of supplying these various accessories, who do not claim nor are they considered as being in the boiler business. As a result of these conditions, the associated details of the problem as affecting the performance of the boiler have been largely overlooked, and it is the practice when the performance and operation of the steam generating apparatus are considered, to commonly use the expression "boiler" although reference is made to the performance of the entire apparatus of which the boiler proper is only a portion. Thus we frequently hear of "boiler" tests that are, in reality, tests of the whole device and its performance, wherein it is impossible to differentiate between the effect due to the individual characteristics of the boiler itself, and that caused by other distinct and separate influences which are entirely independent of it.

The method of making tests of this character consists in determining the amount of water generated into steam, which is done by measuring the quantity admitted to the boiler, applying thereto a cor-

rection, placing the evaporative performance on the basis of atmospheric pressure; also weighing the amount of coal used during the corresponding period of time, the result being expressed in units of evaporation per unit of coal used, which is obtained by dividing the equivalent pounds of water evaporated by the number of pounds of coal employed. This, briefly stated, is the main feature of the process which is almost universally employed to determine, for example, the performance of any of the following features:

1. Value of the boiler itself as to capacity and efficiency.
2. Working of a furnace or stoker.
3. Value of the coal.

Or again, if it is desired to ascertain whether the fireman or furnace operator is a good man or not, the same method of procedure is employed; therefore a further object of such test is to determine the

4. Skill of the fireman or furnace operator.

Having the above in view, a brief consideration would indicate that there must be other influences bearing upon the results, of equal importance to the individuality of the boiler, which suggests the desirability of ascertaining the measure of these different influences. In addition, it is advisable in making reference thereto, that some new and adequate terms be devised and adopted, that there may be intelligent differentiation made between the influence due to the component parts of the steam generating apparatus, because it will no longer be feasible to use the word "boiler" as applying to these several distinct and separate, although associated features.

In the early experience of the testing of "boilers" (steam generating apparatus), when the problem was not so fully understood as at present, experience frequently showed when a test was repeated under supposedly the same conditions, that the results differed, in consequence of which an effort was made to eliminate supposed errors of measurement and observation. This led to the practice of removing all of the fire and starting it anew with wood and coal which had been previously weighed.* This custom, however, was indulged in before it was realized that the condition of combustion, or in other words, the quality of the fire† was a matter of much importance. Thus the disposition was, while overlooking the chemical features of the problem, to insist upon the exercise of greater care as affecting the physical

* Trans. American Society of Mechanical Engineers. Vol. XXI., p. 34.
† Proceedings National Electric Light Assn. 1903, p. 196.

characteristics, but notwithstanding such precautions, results were no more concordant than before, and there has been a growing desire among mechanical engineers who have thus far dealt with the problem of boiler performance, to attack it in detail. It is, however, a fact, that the one phase of boiler performance, interposing probably the greatest difficulty for engineers, is that of combustion, which is a chemical rather than a mechanical process, and owing to this fact the efforts of engineers have been hampered. Thus it appears that the general problem is a more complicated one than was formerly considered, and it may be that the following will assist to a better understanding of the detailed features involved.

Only a brief consideration is necessary for it to be realized that the office of the boiler is to abstract heat from hot gases flowing over it; hence a boiler, able to abstract a greater proportion of heat from gases of the same character and composition, must necessarily be looked upon as the more efficient boiler. In tests, however, it would be impossible to definitely determine which of the two boilers would be the more efficient, unless each were served with a combustion gas identical in character and composition, because while the boilers might be precisely the same, a difference in the condition of combustion in itself, would result in a higher or lower efficiency in steam generation. Thus studying the matter progressively, commencing with our present viewpoint, it is desirable that if values are to be expressed in some term of "efficiency," the beginning must be made with the boiler itself, and when its own efficiency, strictly from the standpoint of its own individuality has been located, it will be feasible to take up other steps in the consideration. It is a fact that there is as much variation in efficiency in steam generation, due either to the working of a stoker machine, the character of the fuel, or the skill or ability of a fireman or furnace operator, as to the boiler itself. Therefore these features are of equal economic importance to that of the boiler performance, and it is as desirable to have some means for measurement of their value as it is of the boiler proper.

The next step is that of combustion, and if complete combustion of all of the fuel which does not fall into the ash pit occurred with no air in excess, the performance would be ideal, and the condition could be referred to as giving efficiency of combustion of 100 per cent. It must be observed that this implies that a maximum temperature has been generated, as would necessarily follow, as there would be no

air in excess, thus any definition of efficiency of combustion must take into account initial temperature.* It would not be sufficient that there were no carbon monoxide or hydrocarbons present in the combustion gases for the ideal condition to be obtained, because combustion could be complete if accompanied by very large excess of air, but the initial temperature would be so low, that the heat in the gases would be very largely wasted in the chimney. Thus the office of the gases is to heat something, and to heat it to advantage they must be hot, and it should not be lost sight of, that the hotter they are the more heat will be delivered. This individual branch of the subject should be considered as a combustion performance rather than the performance of a furnace, because it is found that the shapes of setting walls, combustion chambers, etc., exercise an influence, and it would be desirable to understand this and apply a measure of value. For example, if a fire discharges its gases into a chamber, which is sufficiently long to insure that combustion be completed before the exit of the gases, its performance could be referred to as having an efficiency of 100 per cent., but if of shorter length and combustion unfinished, its efficiency would be proportionately less.

The next step leads to the consideration of the stoker or firegrate, and the problem becomes more complicated. Thus an ideal stoker would be one introducing the fuel in such manner that there would be an equal mixture between products of combustion and entering air for all portions of the fire, and at the same time not allow unburned coal to fall through into the ash pit below. This would require a replenishment of the fire by depositing fuel equally over its entire surface, something, which in best service is impracticable for three reasons:

1. That it is difficult to so distribute the fuel;

2. Under this condition, volatilization would occur equally over all portions of the fire, which would necessitate a correspondingly larger combustion chamber;

3. With such method of feed, the ash would have to be removed from the bottom of the fire, which would be impossible without disturbing the entire fuel bed.

Therefore the best result would be obtained by the admittance of fresh fuel at a uniform rate at one end of the stoker fire bars, and at the same time, discharge of ash at the other end. Thus the volatil-

* Trans. American Society of Mechanical Engineers. Vol. XXVI., p. 643.

ization occurs at one side of the fire, from which portion smoke making gas will enter the combustion chamber, where the completion of the combustion process should occur, therefore it appears that the duties of the stoker are to produce uniformity in supply of fresh fuel, maintenance of the fuel bed, proper and adequate discharge of the ash, and that there shall be an absence of air leaks through the frames or other parts of the stoker machine. The ability of the stoker to perform these offices is the measure of its efficiency, and it is of no consequence whether smoke making gases are discharged by it or not, because it is the office of the combustion chamber to finish their combustion.

But it is often found that a different character of fire is produced with the same stoker, due to variation in quality of the fuel.* Therefore it is necessary to go a step further, and take into consideration another influence which has a most significant bearing on the problems, although one entirely disassociated with any characteristic of the apparatus itself, because if the best character of apparatus be served with the poorest kind of coal, the final result will be a correspondingly poor one, while on the other hand, it is possible to attain a higher result in steam generation if an inferior apparatus be served with the best coal. Likewise, if the furnace operators or firemen are careless or unskilled, they may influence the result in a manner equal to that due to variation in the character of the fuel itself, through such causes as failure to clean the fire, maintain a sufficiently thick fuel bed, or allow the fire bars of the stoker to become uncovered, etc. Thus it is apparent that there are two classes of influences bearing upon the final result:

1. Of the apparatus itself.
2. The fuel and manipulation of the fire.

Thus enumerated the characteristics of the apparatus as a whole are as follows:

1. The boiler.
2. Process of combustion.
3. Performance of furnace.
4. Action of stoker.

It is assumed, of course, that setting walls, etc., would be carefully built so as to eliminate the necessity for consideration of air leaks or radiation therefrom, although these are problems of sufficient import-

*Journal Western Society of Engineers. Vol. XI., p. 529.

ance in themselves to require adequate attention. While on the other hand, the influences which are no part of the apparatus itself, but have an equal effect in the final result, are enumerated as:

1. The characteristics of the fuel.
2. The result of skillful or unskillful manipulation of the fire.

It therefore follows that the proper measurement of the efficiency at any stage of the process must not be vitiated by variables introduced from elsewhere.

While it is a comparatively simple matter in a general way to call attention to the deficiencies of present established methods of considering boiler and furnace performance, it is a more difficult problem to suggest improvement, for the reason that proper standards for comparison have not been established. But for practical purposes, the matter may at present be divided broadly into two departments, one under the head of Boiler Performance, the other, under that of Furnace Performance, and the boiler may be tested by one of the following three methods:

If it be assumed that 12 per cent. CO_2 be considered to represent a standard condition of air supply with complete combustion; and that a good boiler with such condition of combustion, when working at the rate of 1 H.P. per each 10 sq. ft. of heating surface cools the gases to 85° F. above steam temperature, it will represent approximately the best performance thus far attained. Thus the standard conditions would be—complete combustion, 12 per cent. CO_2 by volume, and rate of working equal to 1 H.P. per each 10 sq. ft. of water heating surface; and the standard result—85° F. in escaping gases above steam temperature. Thus comparison between various boilers would appear in a difference in final gas temperature. Efficiency could be determined by referring the initial temperature of combustion to the final gas temperature. For illustration, steam temperature in the boiler is taken at 366°, and if the initial temperature be considered as 2,600° F. and the final as 451, the efficiency is:

$$2{,}600 - 451 = 2{,}149, \text{ and } \frac{2{,}145}{2{,}600} = 82.65 \text{ per cent.}$$

Or if the final temperature is 600° F., the efficiency becomes 76.92 per cent.

The elevation in temperature of the escaping gases is the result of two causes,—one, due to the steam pressure that sets a limit, below

which there can be no further cooling; the other, the measure of the inability of the boiler to cool the gases. Therefore the boiler should not be charged with the elevation due to steam temperature. Then if it cool its gases to the temperature of the steam, the efficiency of the boiler would be 100 per cent. On this basis, which is in reality the correct one, two boilers, for illustration, may be considered as follows:

	Boilers	
	A.	B.
Initial temperature, Deg. F.	2,600	2,600
Steam pressure, pounds	150	150
Steam temperature, Deg. F.	366	366
Final gas temperature, Deg. F.	451	600
Final gas temperature above steam temperature, Deg. F.	85	234
Reduction in temperature of gas by boiler, including steam temperature	2,515	2,366
Efficiency of boiler, per cent.	96.73	91.00

Another method, assuming complete combustion and a standard air supply as shown by the per cent. CO_2, consists in operating the boiler at some standard horsepower capacity, such, for example, as the development of a horsepower for each 10 sq. ft. of heating surface and comparing the absorption of heat as determined by the amount of water evaporated with some accepted boiler performance, which is the same as the method recommended by the Committee of the American Society of Mechanical Engineers,* except that it demands that the condition of test be the same for all boilers, which would also require that a uniform steam pressure be used in test, that a standard condition of combustion be employed, and that the boiler be worked at some standard capacity, if the purpose of the test is to determine its efficiency. If the object is more particularly to ascertain its capacity, it should then be operated at some standard efficiency, or in other words, at some rate at which the temperature of the gases leave at a standard rise, such, for illustration, as 85° F. above steam temperature.

A third scheme has been suggested by Mr. W. T. Ray, of the United States Geological Survey. It consists in maintaining the boiler under pressure of steam which is supplied from some other source, the condensed water in the boiler being drained away as fast as it accumulates. Instead of maintaining a fire under the boiler, a known quantity of air is forced through it by means of fans; observations of the initial and final temperature of this air, together with

*Vol. XXI. Trans. American Society Mechanical Engineers.

the amount that has passed through the boiler, gives data, from which the heat absorbed may be determined. This scheme reverses the process, inasmuch as the boiler is used to give up heat rather than to absorb it, but a good boiler would give up more heat to the entering air than a poor one, or in other words, it would act as the better heater. Thus this heating effect which referred to some known or accepted standard, would afford a basis of comparison as to value for the boiler.

The furnace proposition is more complicated, but by the elimination of certain unessential factors, the problem may be dealt with. For example, if combustion is complete, efficiency of combustion will be dependent entirely upon the amount of the air supply. Thus with the minimum supply, maximum temperature will be realized and efficiency of combustion will be at its highest. Therefore, under these conditions, the actual temperature may be referred to the theoretical maximum, or to some standard temperature which is a reasonable amount lower. But when combustion is incomplete, the loss due to heat escaping in unburned hydrocarbons, presents a serious difficulty. Inasmuch, however, as the employment of a furnace apparatus which allows incomplete combustion to proceed, is unnecessary, the problem of determining furnace efficiency may be simplified by demanding a condition of complete combustion. Then, if it be assumed that a standard temperature of combustion of 2,600° be adopted, and in practice only 2,400° be realized, efficiency of combustion as compared with the standard:

$$\frac{2{,}400}{2{,}600} = 92.31 \text{ per cent.}$$

When it becomes necessary to determine the loss of incomplete combustion, owing to the difficulty of analysis for hydrocarbons, it is necessary to make comparative heat measurements, using some standard boiler as a calorimeter.*

The efficiency of the stoker should not be determined by any result in water evaporated, but by its ability to properly feed and burn the required quantity of coal, and do so with a minimum waste through its grate bars.

*Jour. Western Society of Engineers. Vol. XXXIII., p. 209.

THE EXAMINATION OF FLUE GASES IN BOILER TESTS *

By

H. AUGUST HUNICKE †

A boiler test is made with a view to determine either the capacity and efficiency of a boiler plant or that of a fuel. In both cases careful observations must be made to determine the distribution of the heat liberated by the process of combustion. Inasmuch as the combustion of the fuel is the source of energy, the efficiency of any boiler plant is primarily dependent upon the efficiency of the process of combustion. It has become a general custom to evaluate a fuel by its so-called calorific value measured in calories or B. T. U.'s. Obviously the B. T. U.'s represent the capacity of the fuel for work. The efficiency of delivery of this potential energy is measured by the intensity at which the latter is set free. The intensity factor of thermal energy is temperature, and the higher the temperature produced by a thermal phenomenon the more available the energy ordinarily becomes for economic purposes. A boiler test, therefore, made for the purpose of evaluating a fuel is in just so far a true measure of the capacity of the fuel as it permits the free development of the highest thermal potential the fuel may be capable of developing. The limitations of any particular boiler in this respect are clearly defined primarily by the relation of the furnace to the boiler, that is the boiler setting, on the one hand and the degree of completeness of combustion on the other hand. A great many factors enter into the process of steam-making but they may all be brought under two fundamental processes, that of combustion or liberation of heat and that of transfer of heat. The latter involves problems of a purely physical nature, while the former is clearly a chemical phenomenon.

The ultimate aim of any firing process is the putting to a useful purpose of all the heat liberated. The more complete the combustion is the greater the returns in heat units. It is therefore a very important matter to determine the extent to which combustion has been completed under the conditions prevailing in a given boiler plant. Incompleteness of combustion may be due to many causes, such as

*This paper was published after the death of Dr. Hunicke. It may contain errors which would have been corrected if Dr. Hunicke had read it.

†Deceased April 7, 1909.

insufficient supply of air, insufficient contact with air due to lack of thorough mixing, premature cooling effect on the mixture of combustible gases and air, etc. Given the composition of a fuel, the law of conservation of mass places us theoretically in a position to determine with precision, by an examination of the resulting gases of combustion, the degree of completeness to which the combustion process has been carried. It may be said that the entire history of a combustion process may be read from the analysis of the products of combustion. In practice our position is, as usual in all complex cases, not so firmly founded as might be desired.

It seemed a matter of great interest to test the extent to which an examination of the flue gases will yield information as to the manner in which a firing process has been conducted. The very extensive work of the Fuel-Testing Plant of the United States Geological Survey appeared to offer an unusual opportunity to investigate this subject.

After careful study of the data of the government report it soon became apparent that the variations of the firing process could not be followed by the individual analysis of the combustion gases made at intervals during each boiler test. This was disappointing, because it was really the original purpose of the investigation. However, while a detailed study of each boiler test was not possible, some interesting features were revealed by a study of the averages of the flue gas analyses.

The chemical aspect of a combustion phenomenon is greatly obscured by the complexity of the fuel. While fuels of relatively simple composition, such as coke, charcoal and anthracite among the solid fuels and water gas among the gaseous fuels, offer no difficulty in the study of the combustion phenomenon from a chemical point of view, the soft coals, the ordinary bituminous coals or lignites, introduce factors which complicate matters very considerably, especially when combustion is not complete. The products of combustion of a simple carbon fuel can, of course, only be carbon dioxide and carbon monoxide, accompanied by more or less oxygen and nitrogen, depending upon the manner in which the combustion has been conducted. It is a simple chemical problem to calculate from the analysis of the flue gases the amount of air consumed and the amount remaining unconsumed in the gases. In the case of simple gases, operations are similarly revealed by an analysis of the products of combustion. Fuel consisting, as does bituminous coal, of constituents which break up

under the influence of heat alone into a volatile portion and a solid residue consisting essentially of carbon and incombustible matter, will behave in a manner quite different from the other more simple fuels. There will be periods of gasification when the air supplied to the grates meets only gaseous products evolved from the coal. During such periods complete combustion will yield products whose composition will reveal the relation of the original gaseous mixture and the air supplied to it. Any incompleteness of combustion will be revealed by the presence of carbonic oxide and unburnt hydrocarbons. At other times the complex fuel will have been completely deprived of its gas-forming constituents, and then the process of combustion will be as simple as that of the simple carbon fuels. Neither of these two, more or less, well-defined periods perhaps ever prevails independently of the other, so that the products of combustion in all cases will be the result of both processes going on at the same time.

The fundamental principle upon which a study of the flue gases is based is the constancy of the ratio of the sum of the volumes of oxygen and carbon dioxide to the volume of nitrogen. As the volume of the oxygen in the air is 20.93 per cent. of the whole, the sum of the volumes of oxygen and carbon dioxide in a flue gas, omitting all interferences for the time being, should be 20.93. The term "oxygen equivalent" will be used for the sum of volumes of oxygen, carbon dioxide and one-half of carbon monoxide calculated to its equivalent in oxygen, as a means of comparison in this study of flue gases. Attention must also be directed to the fact that flue gas analyses do not represent the exact composition of the gases, because all of the hydrogen burnt to water is eliminated before the sample is measured for analysis. Sulphur dioxide, at least where only small quantities are involved, will be washed out of the gases before analysis is begun, larger quantities of the gas would in part be recorded as carbon dioxide, being absorbed by the caustic alkali used for the determination of carbon dioxide. Unfortunately, the same must be said of carbon dioxide, which, perhaps not to the same extent, may also be in part washed out of the gas in the process of collection, though much care is exercised to avoid this loss of carbon dioxide by all careful analysts. At best, a flue gas analysis is only an approximation, and the difficulties of obtaining analytical results which represent the exact composition of the gases as they leave the flue make all calculations based upon them mere approximations. However, in spite of all the difficulties, it would seem interesting to investigate the extent to

which information, as to the conduct of a firing process, can be derived from the results of the flue gas analyses.

The lower group of graphs in figure 1 represent the results of a series of calculations based upon the data of seventy-eight boiler tests. The heavy line was obtained from the experimental results by adding the percentage volumes of oxygen, carbon dioxide and one-half the carbon monoxide. The value of carbon dioxide recorded had to be multiplied by 1.0061 (44.268 ÷ 44) in order to correct for the differences of volume obtained by the use of the experimental value of the density of the carbon dioxide (44.268 when oxygen is taken as 32) and the density deduced from the atomic weight involved ($C = 12$, $O = 16$, $CO_2 = 44$), the change from weight to volume making this correction necessary. The amount of carbon monoxide in nearly all tests was too small to make any similar correction necessary, and therefore its oxygen equivalent was obtained by dividing by two.

All calculations were based on the value of Morley and Rayleigh.

The ratio of hydrogen to oxygen is given as 1 : 15.8792 + .00032 by Morley, or O : H = 16 : 1.00761. At 45 degrees latitude, 100cc oxygen weigh 1.42815 grams and 100cc hydrogen weigh .08987 grams.

Using Morley's value of weight of oxygen, the following table was calculated:

	1 Kg. at O and 760mm. Cubic Meters.	Cu. Ft. in 1 Pound.	1 Cu. Ft. Weighs Pounds.
Air	0.773538	12.391236	.080702
Oxygen	0.699815	11.210274	.089204
Nitrogen in air	0.795733	12.746775	.078451
Pure nitrogen	0.798072	12.784244	.078221
Carbon monoxide	0.799811	12.812100	.078051
Carbon dioxide	0.505871	8.103502	.123403
Hydrogen	11.127184	178.245311	.005610
Water	1.243248	19.915478	.050212
Suphur dioxide	0.349577	5.599843	.178576
Methane	1.397436	22.385402	.044672

Rayleigh's values of densities

FOR OXYGEN = 32.

Air	28.950
Nitrogen in air (nitrogen + argon)	28.1425
Pure nitrogen	28.060
Carbon monoxide	27.999
Carbon dioxide	44.268

Conversion factors used:

1 pound = 0.453593 kilo. 1 cubic meter = 35.3156 cu. ft.
1 kilo = 2.20462 lb. 1 cu. ft. = 0.028316 1c b.m.

Cubic meters in 1 kilo times 16.01891 = cubic feet in 1 pound.

Inasmuch as the situation does not permit a direct attack of the problem, it became necessary to make certain assumptions defining limiting conditions as they exist when all other factors are eliminated. A great number of assumptions may be made, the simplest, however, is that the hydrogen and carbon of the fuel are oxidized to water and carbon dioxide to the extent indicated by the analysis. The latter records the amount of carbon dioxide resulting from the combustion while the water is eliminated by condensation, thus not appearing in the gas analysis.

Let C = percentage weight of carbon in fuel.
H = percentage weight of hydrogen in fuel.
O = percentage weight of oxygen in fuel.
N = percentage weight of nitrogen in fuel.
S = percentage weight of sulphur in fuel.

Case 1.—The oxygen by weight required for complete combustion equals (8/3 C plus (8 H minus O), and therefore the total nitrogen resulting from the complete combustion of the fuel is equal to (8/3 C plus (8 H minus O) times 3.31 plus N.

The carbon dioxide resulting from complete combustion equals 11/3 C.

For perfect combustion the maximum percentage volume of carbon dioxide in the flue gas is equal to (11/3) C times 8.10) divided by 12.55 times (8/3 C plus (8 H minus O) times 3.31 plus N) plus (8.10 times 11/3 C).

A small correction must be made in this value in order to obtain the oxygen equivalent. This is done by using instead of the conversion factor 8.10 for carbon dioxide 8.10 times 1.0061 = 8.15 and yields a value M.

Or in the form of an equation:

$$3.31\ \frac{2 + 16\,C}{12} + \frac{16}{2}\,H - O + \frac{2 + 16}{32}\,S + N.$$

The volume of oxygen equivalent to that contained in the carbon dioxide found is equal to that volume times 1.0061. This volume plus the volume of the oxygen found by analysis plus one-half the volume of carbon monoxide found is equivalent to the volume which would

be occupied by the oxygen contained in the three gases determined, if not in a state of combination.

Case II.—In practice neither is combustion complete nor are all combustible constituents of the fuel consumed. Few coals leave an ash free from carbon. Greater accuracy in the calculated value of oxygen equivalent might be expected by correcting for the loss of carbon in the ash. As more or less flue dust always accompanies the operation of combustion as ordinarily conducted, this may also be included in the correction. While it is not fully justified to assume that the flue dust contains the same amount of carbon as the ash, it was nevertheless decided to make the assumption, because it was thought that, however free from carbon the thoroughly burnt flue dust may be, losses of carbon are also due to soot which is carried off with the flue dust and is weighed as such. In the total averages of all tests this calculated value most closely approximates the results of analysis, and was therefore used as a basis of comparison. No importance should, however, be attached to this preference.

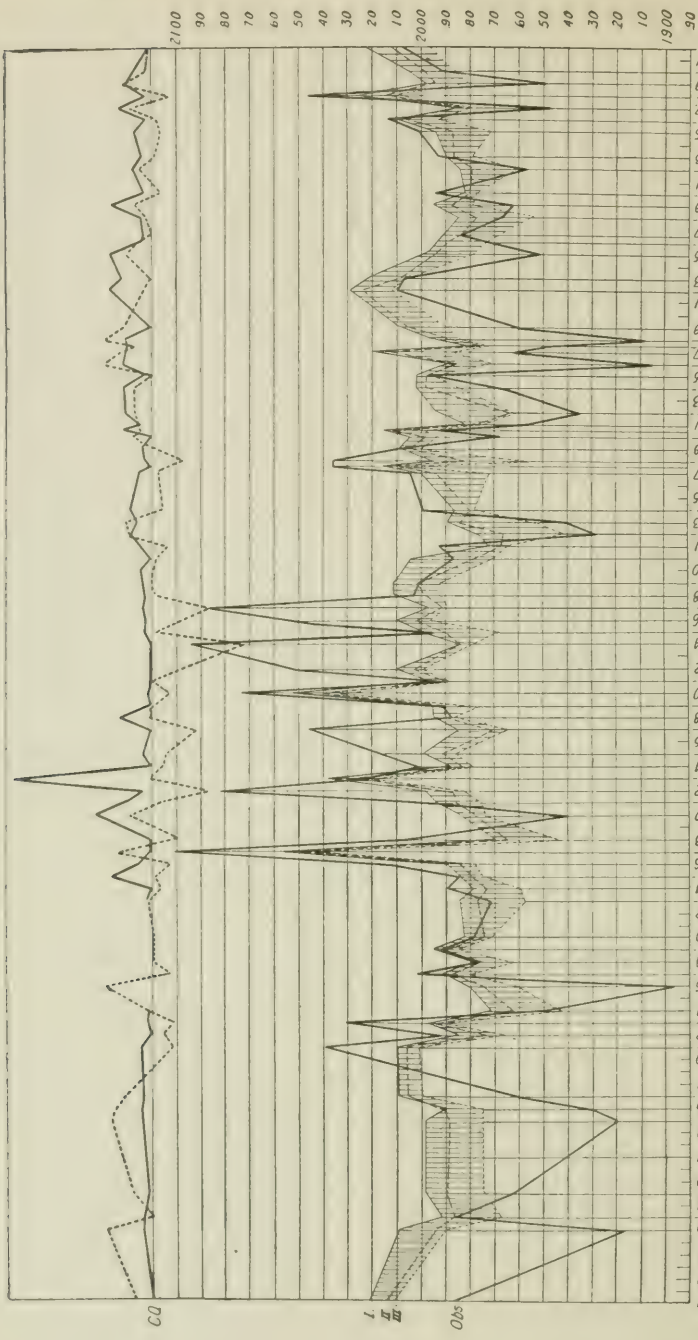
Case III.—Many coals operated upon in the tests under consideration contained a not inconsiderable amount of sulphur, and while it is well known that this element may occur in a coal in various forms so that not all of it is burnt to sulphur dioxide in the process of combustion, it was nevertheless assumed that this was the case, because it was desired to know the extent of maximum deviation of the oxygen equivalent resulting from the assumption which caused the most extreme deviation from experimental results. In all cases where the sulphur is only partially burnt or not at all because it is present in some form not subject to higher oxidation, the oxygen equivalent will be found to be more nearly equal to that resulting when no account of sulphur is taken. It was assumed in the extreme case that all sulphur was eliminated from the gases by condensation with the water, so that it formed no part of the volume of the sample of the flue gas analyzed.

These three values of oxygen equivalents thus obtained were plotted as shown in upper line of figures of figure 1. The space between the graphs is shaded and represents the range of variation of the oxygen equivalents for the various fuels where combustion is complete to the extent the experimental results would indicate. The results of the flue gas analyses as recorded in the report do not include any determinations of unburnt hydrocarbons which may and usually are to a greater or less degree present in flue gases resulting from the

combustion of bituminous or gassy coals under the ordinary conditions.

A comparison of the values obtained by analysis and those resulting from the application of the method of calculation as described above, shows that while a number of the calculated values are very close to the experimental values, there are a number of values which deviate, in some cases very considerably, being either short of the calculated value or in excess of the latter. All oxygen equivalents smaller than the calculated values would seem to indicate that either more or less unconsumed gas had reached the flues, and appears in the analysis as "nitrogen," or else that the samples analyzed were taken mostly during the period of gasification, when a greater preponderance of hydrogen would reduce the oxygen equivalent. The former case can presumably hardly be said to have prevailed to any great extent, because the analyst would doubtless have determined the amount of unconsumed hydrocarbons remaining in the flue gas. It is therefore more probable that the discrepancy is due to the second cause. This discovery is rather disappointing because, while such deviations were expected in the individual determinations, and it was hoped that the progress of the combustion could be followed by just such deviations, yet no such results were looked for on the averages of entire tests extending over many hours. The number of flue gas analyses made during each boiler test were presumably too few and ill-chosen to permit the use of the results in the sense of representing true averages of the entire test.

In the upper part of the chart are plotted side by side the averages of the carbonic oxide as found by analysis and indicated by a heavy line, and the deviations of the oxygen equivalents indicated by a dotted line. The latter values were so plotted that the negative deviations were plotted upwardly in the direction of the carbonic oxide values, while the positive deviations are plotted negatively (downwardly). It cannot be denied that there exists a parallelism, which must be construed to mean that in the case of negative deviations combustion was incomplete, a deduction entirely in accord with the carbonic oxide determinations; while on the other hand, the positive deviations would indicate that there has been an over-oxidation, a phenomenon not known in connection with the process under consideration. The question then arises, how to account for oxygen equivalents deviating from the experimental results which are greater than those obtained by calculation. We again have the choice of two interpretations, either the samples represented predominatingly the period of coke combus-


2100
2000
1900
CO
SO2

tion; in other words, that an insufficient number of samples were taken during the gasifying periods, or else that more particularly perhaps the hydrogen determinations in the fuel analysis, which latter forms the basis of the calculations, are in error. The former interpretation is doubtless, in most cases, justified, and merely corroborates the deductions already made from the negative deviations. Evidence which would seem to indicate that the hydrogen determinations of the ultimate analyses are not entirely trustworthy in all cases is not sufficient to draw any definite conclusions. The oxygen determination of fuels, being obtained by difference, is necessarily totally unreliable. Some effort should be made at an oxygen determination, and there should be sought more complete knowledge of the discrepancies due to incorporating into the ultimate analysis the ash without corrections, which are necessary in consequence of the assumption that it forms, as such, part of the original 100 per cent. of the coal.

Perhaps it will be argued that it is hardly justifiable to use the data given in the report of the survey in the manner indicated above, but it must be admitted that any complete set of data such as that referred to must bear the searching test of a balance sheet, not only of the B. T. U.'s, but also of the chemical masses which enter into the process. There seems certainly to be some unjustifiable element of uncertainty, due either to the analyses of the fuels or else to those of the flue gases. It seems hardly justified to assume that the extreme variations of the oxygen equivalents should have to be accounted for entirely by the limited number of samples of the flue gases. When it is observed that the variation of the theoretical values of the coals under consideration at no time reaches such extremes as do a number of the experimental values, all of which represent averages of extended periods of operation and not individual determinations, it becomes evident that even the averages of the flue gas analyses of the various tests are in many cases open to serious criticism. Evidence can be cited that at least great care was exercised in drawing the gas samples for analysis. Whether the same may be said of the gas analyses is a matter of some doubt.

Without data of far greater completeness, any attempt at using the analyses of flue gases for extended researches into the study of the combustion process must fail. It is not necessary to add that the demand for greater accuracy applies to technical research such as that embodied in the report of the U. S. Geological Survey rather than to the commercial tests where greater accuracy than that necessary to

secure practical information is of no purpose. Greater care should doubtless be exercised in the chemical work of such extended series of boiler tests as those of the Survey, because it is impossible to foresee what information may at any time afterward be drawn from the data. However technical may be the work in its grosser features, elements which are measured should be measured with precision. It is to be hoped that in the future more powerful methods will be brought to bear on the problem in order to insure not only accuracy of a high order, but also data which will most certainly yield information urgently needed as the competition between the different methods of fuel utilization becomes more keen.

The question of sampling has been too thoroughly discussed to require further reference at this occasion. Just a few words may, however, be permissible. The difficulty lies primarily in securing samples of gas which represent a definite period of the process, be it long or short. It has been the common practice to draw samples extending over long periods of time in order to secure samples of more average composition. Perhaps as the technique of gas analysis becomes more highly developed it will be found more satisfactory to make a great number of determinations on samples representing only short periods of time of known duration. Already the latter method is applied where carbonic acid recorders are used, and doubtless much of the value of these latter instruments is due to the greater frequency of the determinations.

In conclusion it must therefore be said that the data furnished by the report of the Geological Survey, which, it is assumed for want of something better, represent the present state of our knowledge on the subject, are not sufficiently reliable to draw from them information as to the management of a firing operation any further than the carbon dioxide, and perhaps also the carbon monoxide, determination warrants. We are still no farther advanced in our potency in this direction than we already were, except that we can utilize our powers to the fullest in our customary methods of conducting boiler tests. Carbon dioxide recorders are doubtless invaluable as important elements in the recording of the performance of boiler plants, but we cannot for the present hope to gain information in greater detail than that most valuable instrument already records, unless technical research be directed to throw more light on the subject.

TABLE 1.*

No.	Observed.	I.†	II.‡	III.¶	O_2.	CO_2.	CO.
17	19.78	19.82	19.74	19.71	11.43	8.30	....
21	20.15	19.89	19.84	19.78	11.65	8.40	0.1
16	19.92	19.95	19.90	19.85	11.69	8.18	....
	19.95	19.89	19.83	19.78			
9	20.40	20.10	20.06	20.01	12.31	8.00	0.08
14	20.02	19.91	19.87	19.80	10.57	9.37	....
8	19.61	20.09	20.05	19.99	11.40	7.74	0.06
11	20.31	19.97	19.95	19.92	11.81	8.44	0.03
29	20.16	19.99	19.91	19.86	11.17	8.90	0.07
35	20.51	20.10	20.03	19.99	12.94	7.52	0.00
40	20.03	20.11	19.98	19.92	11.08	8.87	0.05
42	19.86	20.04	19.77	19.70	11.97	7.84	0.00
41	20.01	20.11	20.02	19.92	11.62	8.29	0.09
	20.10	20.05	19.96	19.90			
75	20.47	20.26	20.14	20.13	13.76	6.64	0.05
18	19.71	19.84	19.77	19.57	11.14	8.50	0.04
19	19.89	19.78	19.73	19.59	11.40	8.44	0.00
38	20.54	20.10	20.02	19.96	13.38	7.10	0.04
48	20.36	20.16	20.14	20.10	13.20	6.52	0.00
50	20.08	20.09	20.05	20.00	12.60	7.40	0.07
73	20.14	20.11	20.07	19.93	13.65	6.73	0.04
	20.12	20.01	19.96	19.86			
71	19.93	19.90	19.87	19.79	11.02	8.70	0.06
68	19.62	19.96	19.89	19.79	10.43	8.98	0.32
65	19.72	19.93	19.89	19.73	11.98	7.65	0.09
	19.76	19.93	19.88	19.77			

*Second decimal added merely to define first decimal. Experimental values do not appear to be closer than 0.1 or perhaps only 0.2.

†I.—Complete combustion, without correction for ash, sulphur, etc., except CO.

‡II.—Complete combustion, corrected for loss in ash and flue dust and CO.

¶III.—Complete combustion, corrected for loss in ash and flue dust and CO, assuming that all sulphur burns to sulphur dioxide and is condensed with moisture before carbon is absorbed by sodium hydrate.

**Volume of oxygen calculated by adding observed volume of oxygen to 1.0061 times the observed volume of CO_2 to ½ the observed volume of CO.

10	19.91	19.83	19.73	19.65	11.33	8.53	0.00
20	19.84	19.84	19.79	19.74	10.17	9.46	0.31
32	19.91	19.95	19.90	19.76	12.06	7.80	0.00
32	19.93	20.16	20.13	19.99	12.64	7.14	0.21
	19.90	19.94	19.89	19.79			
45	19.41	19.89	19.84	19.53	10.63	8.67	0.12
67	19.67	19.85	19.77	19.54	11.48	8.14	0.09
49	20.36	19.94	19.82	19.55	13.12	7.18	0.04
47	20.04	20.00	19.94	19.72	12.31	7.63	0.10
66	19.84	19.91	19.84	19.68	12.27	7.49	0.06
55	19.68	20.02	19.98	19.85	11.66	7.83	0.28
	19.83	19.93	19.86	19.65			
6	19.19	19.98	19.88	19.74	11.89	7.22	0.07
7	19.31	19.89	19.91	19.94	11.86	7.37	0.08
13	18.96	19.80	19.74	19.60	10.97	7.94	....
3	19.87	19.91	19.86	19.67	12.27	7.52	0.06
4	19.62	19.98	19.89	19.74	12.68	6.89	0.02
58	19.63	20.20	20.13	19.88	13.54	5.90	0.21
72	20.01	19.94	19.87	19.71	12.05	7.84	0.14
	19.54	19.96	19.90	19.73			
60	19.08	19.95	19.88	19.84	10.70	8.22	0.21
57	19.05	19.89	19.85	19.71	10.24	8.64	0.23
76	19.48	19.98	19.95	19.80	10.74	8.59	0.20
64	19.51	19.98	19.94	19.78	10.94	8.45	0.33
62	20.10	20.29	20.24	20.12	13.49	6.40	0.34
	19.44	20.02	19.97	19.85			
12	19.49	19.71	19.62	19.42	10.90	8.53	0.02
23	20.07	19.69	19.64	19.43	11.05	8.97	0.00
16	19.77	19.78	19.75	19.62	11.75	7.97	....
37	19.95	19.98	19.90	19.68	12.52	7.36	0.05
44	19.28	19.76	19.66	19.41	9.65	9.48	0.16
78	20.08	20.23	20.13	19.97	14.62	5.42	0.02
77	19.91	20.05	19.99	19.87	12.48	7.31	0.15
70	19.57	19.84	19.79	19.61	11.53	7.92	0.15
	19.77	19.88	19.81	19.63			
27	20.23	20.38	20.25	20.22	10.07	9.55	1.11
26	20.82	19.98	19.87	19.82	12.95	7.79	0.07
30	20.46	19.84	19.70	19.64	12.66	7.15	0.01
	20.50	20.07	19.94	19.89			

33 .....20.73	20.53	20.43	20.35	15.96	4.74	0.00
1 .....19.86	20.21	20.14	20.11	13.31	6.51	0.00
2 .....19.17	20.17	19.94	19.90	10.90	8.68	0.07
36 .....20.94	19.84	19.83	19.79	13.16	7.14	0.00
74 .....19.48	19.86	19.83	19.79	10.42	8.87	0.27
19.86	20.00	19.93	19.90			
22 .....21.01	20.57	20.48	20.46	17.36	3.63	0.00
24 .....19.41	19.83	19.77	19.73	9.18	9.95	0.44
25 .....20.02	19.93	19.85	19.75	11.63	8.24	0.20
28 .....20.00	19.87	19.83	19.78	11.99	7.96	0.00
31 .....19.87	19.95	19.89	19.88	11.03	8.67	0.24
34 .....19.81	19.95	19.90	19.87	12.08	7.77	0.02
39 .....20.86	19.96	19.91	19.89	12.46	8.31	0.07
43 .....19.93	19.72	19.67	19.64	9.50	10.32	0.09
51 .....19.67	20.04	19.98	19.93	11.29	8.33	0.00
53 .....19.56	19.81	19.77	19.75	10.71	8.75	0.09
69 .....19.95	19.82	19.80	19.77	11.10	8.77	0.06
54 .....19.35	19.94	19.63	19.61	10.50	8.79	0.21
56 .....19.98	20.02	19.98	19.96	11.32	8.58	0.05
46 .....19.99	19.86	19.80	19.78	9.84	10.01	0.16
59 .....19.48	19.80	19.76	19.72	10.18	9.14	0.20
19.86	19.90	19.82	19.79			
63 .....20.07	20.22	20.08	20.05	11.72	8.18	0.25
61 .....19.60	20.09	20.05	19.89	12.98	6.58	0.00
19.83	20.15	20.06	19.97			
Average 19.90	19.98	19.91	19.76			

THE USE OF PULVERIZED FUEL FOR HEATING METALLURGICAL FURNACES

By

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In view of the fact that practically all the Portland cement manufactured at the present time in this country is burned with pulverized coal and that this fuel is also used for the nodulizing of fine iron ores, it seems strange that this method of heating furnaces has not been more generally used in industrial and metallurgical work. The use of powdered fuel offers considerable advantage both in economy and ease of regulation over direct methods or the gas firing of metallurgical furnaces. It is possible to burn powdered fuel with almost the exact amount of air necessary for combustion. This means that a higher temperature can be obtained than is possible with producer gas or solid coal. It also means that the saving of fuel due to the smaller amount of excess air used is considerable. When powdered coal is burned, the ash is free from residual carbon, which means that all the carbon is burned, while with producers and furnaces in which the coal is burned or gasified from grates a portion of the carbon is always left unconsumed in the ash. Furthermore, practically all the carbon is burned to carbon dioxide, avoiding losses due to incomplete combustion to carbon monoxide.

Powdered coal has the advantage over gas firing in that the inherent losses of the gas producer are overcome. These losses are by no means small. It is estimated that the average loss of heat in the gasification of fuel, due to complete combustion to carbon dioxide, heat radiation, etc., is seldom less than 20 per cent. If to this is added the loss due to the carbon which the ash carries away with it and the coal consumed in the boiler for the production of the steam required for the gas producer, it is safe to say that the loss may generally be considered as 30 per cent. of the thermal value of the coal.

The two objections which have been most often raised to the use of powdered coal are the difficulty of its preparation and the danger of explosion. The latter has been very largely exaggerated. Powdered coal suspended in air is of course a very explosive substance. Indeed the energy of a pound of coal in this condition is greater than that of a pound of gun-powder. At the same time, however, powdered coal *en masse*, that is, when it is in a pile or in a bin, burns very slowly and with absolutely no explosive effects. In the earlier days of the use of pulverized coal in the cement industry, a number of explosions took place. Of recent years, however, these have been very infrequent, owing to the fact that the cement manufacturers have found the conditions under which explosions are most likely to occur and have guarded against them. The main principle in each case is to prevent the coal dust from being stirred up and mixed with the air.

The department of the plant in which the coal is ground should always be well ventilated so that no gas can accumulate. This can be accomplished by the use of a monitor running the full length of the roof and having slatted sides, so that any gases which may be generated from the coal will of course rise to the roof and so escape. Reinforced concrete offers a splendid material for the construction of fuel mill buildings, as the walls are straight and there are no projections to catch dust. In order that any fires started in the coal pulverizing department may not be communicated to other parts of the mill, this building should be fireproof and located with at least an alley between it and the other parts of the mill. Stairways, bins, platforms, conveyor troughs and elevator casings should all be made of metal. Platforms and steps should be constructed of perforated sheet steel, as less dust collects on them in consequence. The electrical wiring of the lights, motors, etc., in these places is also carefully installed, no naked lights being allowed in them. Most fires result from attempts being made to repair elevators and bins by the light of the ordinary workman's torch. The hammering shakes the dust from the sides, etc., of the elevator casing or bin and the naked flame ignites the dust-laden air. Warnings against the use of torches, etc., in several languages, with penalty of dismissal, should be displayed prominently about the fuel grinding department, and large signs, *"No Torches in This Building,"* should be placed upon the doors.

When fires occur in grinding mills, they may be best extinguished by the use of a tube of liquid sulphur dioxide (kept for the purpose), or they may be smothered by steam. All this is by way of precaution

only, however, as fires now rarely occur in fuel mills. With a little care along the lines indicated, firing with coal dust may be considered just as safe as any other means of heating furnaces.

As to the process for preparing the coal for the burner, great strides have been made in pulverizer mills of all kinds in the last few years, and it may safely be said that coal can be pulverized at a cost far less than that necessary to convert it into a gas. A little further on in this article we will take up again more fully this question of cost.

Coal-dust heating is well suited to obtaining high temperatures in open hearths. It is possible with this method of firing to get as long a flame as can be obtained with any other. The system was tried on a reverberatory furnace at Murray, Utah, and here it was said that it was possible when allowed to do so for the flame to heat and slag the stack brick.

With a rotary cement kiln 60 ft. long it is possible by closing all dampers to obtain a flame almost the entire length of the kiln. It is also possible by finely pulverizing the coal and using a damper to concentrate the flame within the first 20 ft. This makes the coal-dust flame one which may be very easily regulated so as to heat most strongly just that part of the charge which it is desired to have hottest.

The objection which has been frequently raised to pulverized fuel is the settling of the ash upon the charge, and also the clogging up of the regenerating ovens. In this connection some experiments made by the writer several years ago are interesting. In a rotary cement kiln, 6 ft. in diameter and 60 ft. long, it was found that only half the coal ash fell on the charge and that the other half was carried into the chimney by the draft. The ash of pulverized coal is very light. The particles, of course, occupy practically the same volume as the coal particles, and are only from 10 to 20 per cent. the weight of the latter, consequently they are carried off by the strong draft which exists in most furnaces. At Murray, Utah, where pulverized coal was used to heat furnaces, it is said that the ash dust did at times settle on the charge, but never enough to cause appreciable insulating or blanketing of the latter.

Where regenerative furnaces are used to heat the air for combustion, this ash, of course, may collect in the checkerwork. Where pulverized fuel is used, therefore, the regenerators should be designed with large ash settling chambers and wide passages in the checker-

work. Damour and Queneau in their treatise on industrial furnaces give as their opinion that parallel counter-current regenerators are well adapted for use with furnaces heated by pulverized coal. These regenerators avoid the use of valves, and it is possible with them to clean out the passages for the waste products by a jet of steam or compressed air, or even with small and sharp water jets. Just enough water should be injected to evaporate instantaneously. If this is to be done, care must be exercised to use in the regenerators fire brick which will stand sudden cooling without "spalling." For such regenerators a design similar to a blast furnace hot stove would be advantageous, as these being formed of a series of thin solid walls are easy to clean.

As we have stated in the earlier part of this article, it is possible by means of powdered coal to obtain a much higher temperature than is possible with gas firing.

For example: The theoretical temperature of combustion of producer gas of the composition; CO_2, 5.8%; O, 1.3%; CO, 19.8%; H. 15.1%; CH_4, 1.3%; N, 56.7% burned with 25 per cent. excess air, is only 1,376° C, while the theoretical temperature of combustion of coal of the composition; H_2O, 1.9%; C, 74.9%; H, 4.8%; O, 8.6%; N, 1.4%, when burned with 25 per cent. excess air, is 1,750° C.

It is possible with pulverized coal to use a much lower grade of fuel effectually than can be done with gas producers; for instance, at the plant at Murray, Utah, mentioned above, coal dust firing was adopted because the clinker of the coal used became very hard and massive, at first forming close to the grate-bars and slagging together on the brick walls of the fire-box, then gradually chilling and hardening from the bottom up. This, of course, necessitated a great deal of labor to break them up, get them out and put the fire on the grates again, the operation requiring from 1½ to 2 hours, during which time the producer and furnace were practically idle.

It is also possible with powdered coal to obtain a much more regular heat than can be obtained from producer gas. In the latter case the gas is very irregular in composition unless the producers are very carefully handled, while with the former if improved methods for carrying the coal to the furnace are used it is possible to furnish the furnace not only with a fuel of uniform composition and in regular quantity, but also to so regulate the air as to burn it to the best advantage.

In coal dust firing the best results are obtained by keeping the flame in a chamber in contact with highly heated material such as fire-brick. If the flame, on the other hand, comes in contact with a cold surface, such as boiler tubes, the latter will reduce the temperature of the fuel and the air below the ignition point, resulting in incomplete combustion. For this reason heretofore coal dust firing of boilers has not been used successfully, but there is no reason why, if the proper types of furnaces are used in connection with certain types of boilers, the system of burning pulverized coal in connection with boilers, should not be successful. In the case of metallurgical furnaces, however, where the fire-brick and charge are both at a high temperature, combustion is complete and very rapid.

Coals rich in volatile matter, such as gas coal and lignite, are best suited to pulverized firing. The analyses given below are those of coals from various sections of the country which have been successfully used for burning in a pulverized condition:

ANALYSES OF COALS USED FOR BURNING IN POWDERED FORM.

	Moisture.	Combustible Volatile Matter.	Fixed Carbon.	Ash.
Wellston, Ohio	2.94%	41.96%	42.82%	12.27%
Poor Quality Pennsylvania	1.38	35.04	56.03	6.27
Poor Quality Pennsylvania	2.15	34.20	57.49	6.16
Alabama	7.50	30.70	53.80	8.00
Hocking Valley	0.82	33.76	61.57	3.85
Illinois	6.59	34.97	48.85	8.00
Connellsville, Pa.	2.10	29.63	51.28	16.99
Fairmont, W. Va.	2.32	27.08	47.34	23.26

It is possible, however, to burn coals very much lower in volatile matter than those given in any of the above analyses. In this latter case, it is only necessary to powder the coal very finely.

A saving is effected by pulverized fuel over fuel burned on grates, because chimneys capable of producing sufficient draft to draw the air through the fuel bed must be provided in the latter case. As is well known to engineers, the draft necessary for this purpose is considerable and uncertain, depending upon the nature of the coal. With pulverized fuel all that is needed is sufficient draft to draw the products of combustion through the furnace with the desired velocity, which can usually be accomplished by the use of a short stack.

The method of preparing the coal for burning consists first in crushing it roughly between rolls or in a small pot crusher, and then

drying and powdering it so fine that from 90 to 95 per cent. of it will pass through a sieve having 100 meshes to a linear inch.

In order to get the greatest efficiency from the pulverizing machinery, it is necessary to dry the coal until it contains less than 1 per cent. moisture. For this purpose three or four forms of apparatus are in successful use. Most of them consist of a rotary cylinder around which the products of combustion from a furnace pass. In some of them the gases, after cooling somewhat, work their way back through the cylinder and form a vehicle for carrying off the moisture. These rotary dryers are inclined at an angle. The coal is fed in at one end, and when fully dried falls out at the other. The cylinder is usually provided with shelves consisting of angle irons bolted to the sides and is often divided into compartments. The shelves serve to pick the material up and drop it through the hot gases passing through the cylinder. A good coal dryer will show an efficiency of over 50 per cent. and evaporate from 7 to 9 lbs. of water per pound of coal burned on the grate.

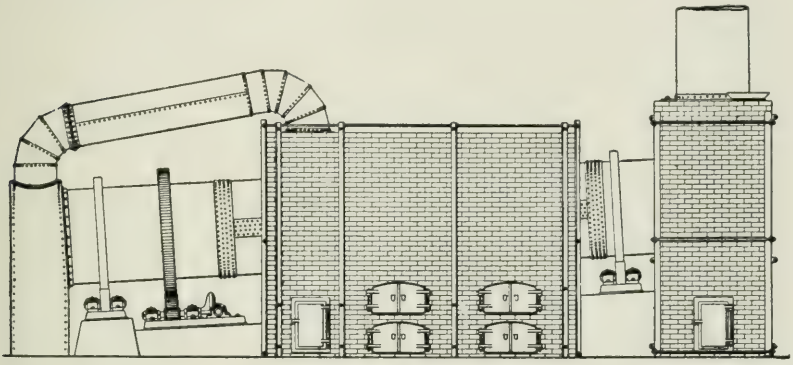


Fig. 1

Fig. 1 shows the Matcham coal dryer (manufactured by the Fuller Engineering Co., Allentown, Pa.), used extensively in the Lehigh cement region of Pennsylvania, where more pulverized coal is burned than in any other single locality in the world, the amount approximating a million tons annually. This dryer, as the cut shows, consists of an inclined cylinder mounted on steel tires which run on rollers. The cylinder is revolved by means of a girth gear and pinion at an approximate speed of 3 to 4 turns a minute.

The cylinder is 30 ft. long and 4½ ft. in diameter. It revolves

partly in a brick housing which contains the furnaces. The hot gases pass up around the cylinder, and this serves to cool them off to a temperature sufficiently low to admit of their being led back through the cylinder by the flue without setting fire to the coal. The gases pass up through the cylinder to the stack. The coal is fed in at the upper end and falls out at the lower. These dryers cost about $3,000 to install. Where hot blast stoves are employed it might be possible to draw off a portion of the air blown through these and diluting it below the ignition point of coal, pass it through an ordinary cylinder dryer into which the coal is fed, and thus dry the latter.

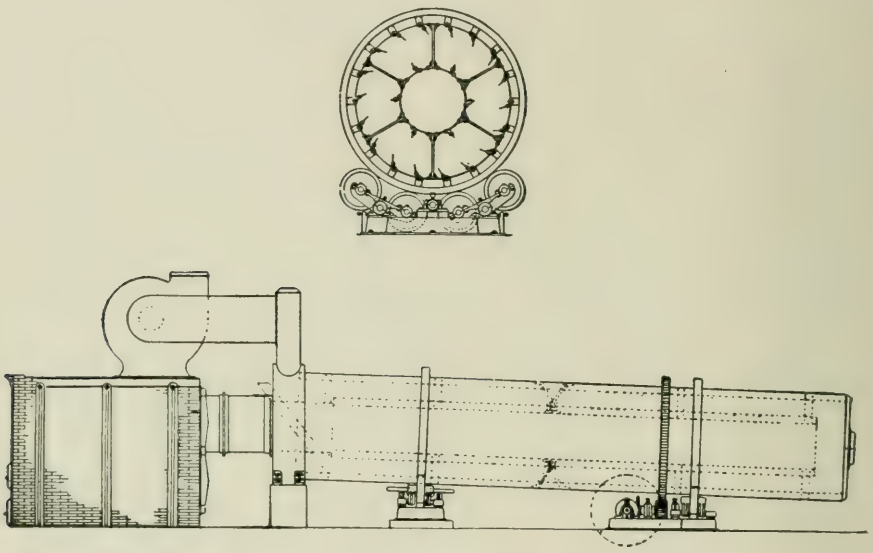


Fig. 2

The *Ruggles-Coles dryer* is shown in Fig. 2, and consists of two concentric cylinders, which are fastened together and revolve on steel tires, supported by bearing wheels. The cylinders are driven by gearing, as shown. The inner cylinder extends beyond the outer one at the head end, and is connected with a brick furnace by a flue lined with fire-brick. The products of combustion from the furnace pass down the central flue, and then back between the two cylinders. The coal is fed into the head end of the dryer between the two shells, and is

caught up by flights on the inside of the outer shell and dropped on the hot inner shell. As the machine revolves, the coal drops from the inner shell to the bottom of the outer one, is carried up by the flights and again dropped on the hot inner shell, etc., until dried. The hot gases of combustion passing up between the two shells also help to dry the material, which is discharged through the center of the rear end. The fan is used in starting to create a draft through the cylinders.

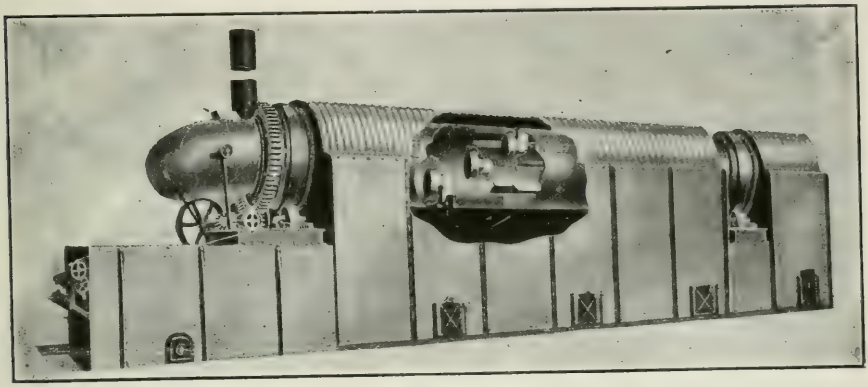


Fig. 3

The *Cummer dryer* is shown in Fig. 3. It consists of an iron cylinder entirely surrounded by a brick chamber. The cylinder is set at an incline and revolves on trunnioned bearings. It is provided with a great many hooded openings, J, so arranged that the heated air and gases of combustion are drawn into the cylinder by means of the fan, G. A furnace provided with a mechanical stoker produces the heat. The hot gases are drawn into the brick work chamber, where they are mingled with air drawn in through the registers, E and O, located at intervals in the brick work side of the chamber, and their temperature reduced by the dilution to a point making it safe for them to come in contact with the coal. The mingled air and gases of combustion are then drawn through the openings, J, and up through the cylinder. The material is fed into the cylinder through the hopper, F, and parts with its moisture as it works its way down through the cylinder to the discharge, K. This dryer is made in eight sizes, with capacities from 50 to 300 tons of coal per day.

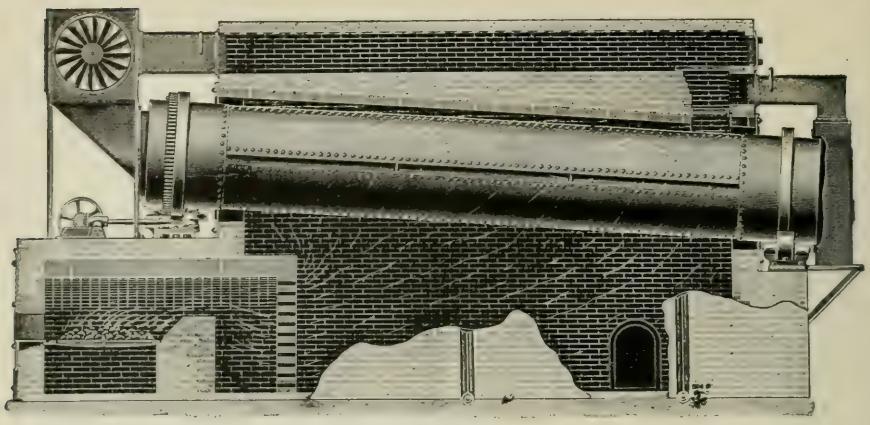


Fig. 4

Fig. 4 shows the *C. O. Bartlett & Snow dryer.* This consists of a cylinder divided into four compartments by passages. The whole is encased in brickwork and revolves on steel tires located at the ends outside the brickwork, as do the other dryers. A furnace is placed at one end and the products of combustion pass from this into the brick casing and travel through this, circulating in doing so around the cylinder and through the passages separating the compartments. The gases do not come in direct contact with the coal, which is fed in at the upper end and falls out at the lower.

Where the coal has been passed through a screen and consists of only pea and slack size, crushing is unnecessary. After being crushed, the coal may be ground, in Fuller-Lehigh Mills, Griffin Mills, or tube mills.

There are a number of mills on the market which are advertised to crush and pulverize coal without drying. One of the best known of these machines is the *Aero Pulverizer.* This is shown in Fig. 5. It consists of three communicating chambers, each slightly larger in diameter than the preceding one, in which revolve paddles on arms, whose length corresponds with the increased diameter of the chambers. A fourth chamber contains a fan which is used to draw the more finely pulverized material from one chamber to the next, and finally to deliver it under the impetus of a forced blast to the burner. The air required for pulverizing purposes is admitted with the coal through inlets, in the feed device. The additional air required for purposes of combustion is admitted between the third work chamber and the

fan chamber, and may be regulated so as to produce either an oxidizing, a neutral or a reducing flame.

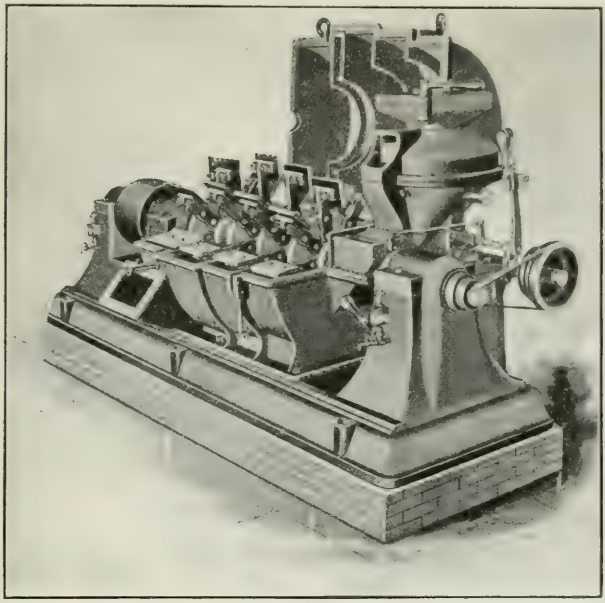


Fig. 5

No dryer is required, and the pulverized fuel is blown directly from the grinder into the furnace by the fans of the machine. From what we can learn of these machines from men who have used them, they do not grind very fine and require about 30-40 H.P. for every ton of coal pulverized. Unless two are installed for each furnace, repairs to the machine necessitate shutting down of the former. For most metallurgical purposes where the gases leave the furnace at a high temperature, there is no economy in grinding coal without drying, and often there is a positive objection to such practice. If the gases leave the furnace at a temperature of say 2,500° F., every pound of steam carries 2,600 B. T. U., while at 400° F., the average temperature of dryer waste gases, the steam only carries off 1,300 B. T. U., or about half as much. Where high temperatures are required, it will also be found much easier to obtain this degree of heat by the use of dry than wet coal. The water, of course, must be evaporated from the wet coal, and this alone utilizes a large number of heat units. The temperature produced in every case is that to which the heat pro-

duced by the burning of the coal will heat the products of combustion. For example, a coal containing 0.3 per cent. water (as it frequently does after passing the dryer) would give a temperature of 3,200° F. when burned with 25 per cent. excess air. The same containing 10 per cent. water would only give 3,000° F. when burned with 25 per cent. excess air. The use of dry coal is analogous to the use of the dry air blast.

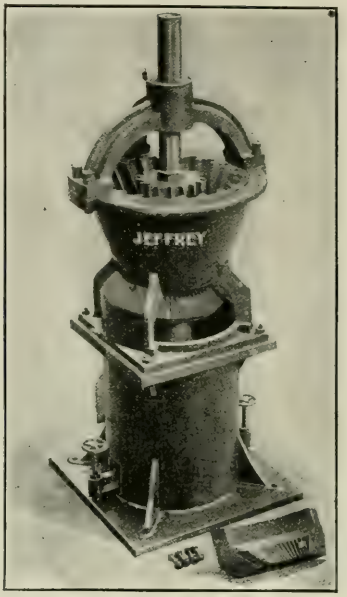


Fig. 6

As we have said before, after passing through the dryer the coal is crushed in a *pot crusher*. One of the best forms of pot crushers is what is known as a "coffee mill cracker." This is shown in Fig. 6. It works upon the same principle as a coffee mill and its action is a grinding one, due to the toothed spindle, rather than a crushing one, and hence it cannot choke up with soft material, as a gyratory crusher would do from the packing of the material between the head and the crushing ring.

When a *set of rolls* is placed before the dryer, they are of the toothed form, such as are used to crush run of mine coal. These rolls are usualy about 24 inches in diameter, with a 30-inch face.

When rolls are placed after the dryer to prepare coal for a tube mill they should be plain-faced or only slightly corrugated. The toothed rolls usually reduce run of mine coal to 2-inch lumps and under, and the plain-face rolls will crush to lumps ranging from ½-inch down.

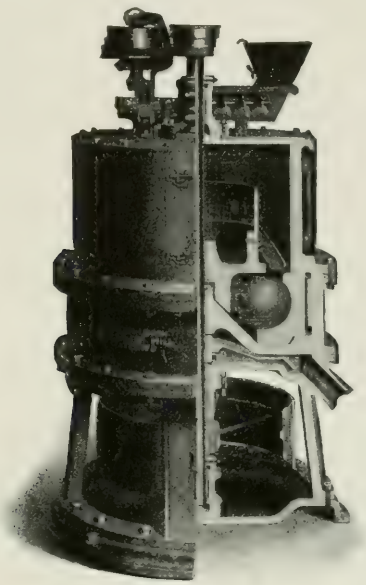


Fig. 7

When coal is first passed through a screen and consists of only pea and slack size, rolls and pot crushers are unnecessary. After being reduced to 1-inch lumps and under, the coal may be ground to the necessary fineness directly by either Fuller-Lehigh Mills or Griffin Mills or tube mills, preceded by some form of preparatory mill, such as a Williams Mill, a Steadman cage disintegrator or a set of smooth-faced rolls.

The Fuller-Lehigh Pulverizer Mill (Fig. 7) (Lehigh, Car, Wheel and Axle Works, Fullerton, Pa.) consists of a horizontal ring or die against which revolve four balls. The balls are propelled by means of pushers. The die and pushers are chilled charcoal iron castings, made of Fuller Special Mixture. The balls are steel forgings, true to size, and are made of a special mixture of steel having high abrasive resisting qualities. These balls are 12″ in diameter and weigh 260 lbs. each.

They revolve at a speed of about 155 R. P. M., and hence press against the die with enormous centrifugal force. The material to be ground is fed into the hopper which serves the feeder. The material discharged by the feeder falls down into the pan of the mill situated below the die and is drawn up from this in between the rapidly revolving balls and stationary die by means of air currents induced by fans placed in the chamber above the die. The material is pulverized by the rolling of the balls against the die, the pressure of each ball against the die being over 2,700 lbs., the grinding action being similar to that of a mortar and pestle. The finely pulverized material is sucked upwards by the fans and held in suspension in the chamber above the die until it is floated out through the screens by means of the fanning action of the fan. The material passing through the screen falls down between this screen and the outer casing, and is discharged from the mill through the discharge spout, which may be placed at any one of four quarters of the mill. The coarse particles, being too large or too heavy to be drawn upward and through the screen by the fans, fall back into the trough, to be again drawn up between the die and the balls. The shaft extends through the top of the mill and actuates the feeding device. The feed to the mill, and consequently the fineness of the products, may be controlled in two ways, either by a slide on the hopper or by means of the stepped pulley, connected to the screw conveyor by gearing. The mill is provided with two screens; one, the inner of 1-inch mesh and made of very heavy wire to protect the outer one. The outer screen does not really screen, but merely controls the draft of air, and hence the fineness, since the greater the velocity the greater the carrying power of the air, and hence the coarser the product. The mills grind to a fineness of 95 per cent. passing a No. 100 sieve with a capacity of four to five tons per hour at an expenditure of 45 H.P. They cost $3,000—and require but little to install, as the foundations are small. The mill is also made in a smaller size (33-inch), capable of producing two to two and a half tons of coal per hour.

The *tube mill*, Fig. 8, consists of a cylinder of steel, from 5 to 5½ ft. in diameter and from 20 to 22 ft. long. It is suspended on trunnions, and is revolved by means of a ring gear and pinion. The cylinder is lined with steel plates or flint blocks, cemented in, and filled to about 6 inches above its middle with flint pebbles. These latter must be very hard and tough, and are usually imported from Greenland and Denmark. The largest of them should not be more

than 3 inches in diameter. The material is fed in through one hollow trunnion by means of a screw conveyor, and works its way through the mill to the other end, where it is discharged through openings in either the end plates or the perimeter of the cylinder. The tube mill makes from 25 to 27 revolutions per minute, and the tumbling about of the pebbles as it does so, grinds the material passing through. The fineness of the product is controlled by the rate at which the material to be ground is fed into it. A tube mill (except in the case of marl)

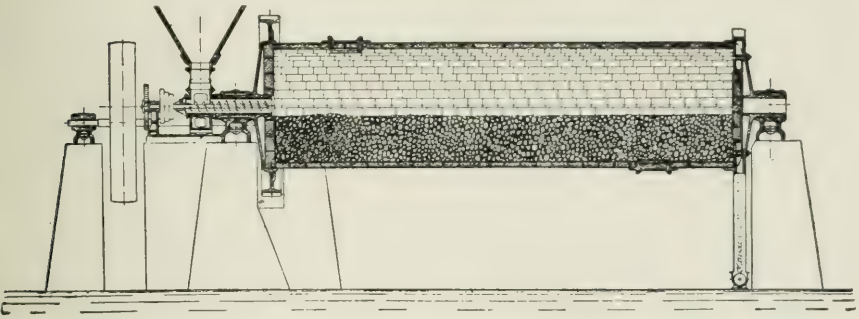


Fig. 8

always works upon material partially ground by another mill, usually in the case of coal, a set of rolls or a *Williams Mill* or a *Steadman* disintegrator. A tube mill requires about 80 H.P. to run, and will pulverize from 2 to 3 tons of coal per hour, 92 per cent. fine, through the No. 100 sieve. The tube mill is not very economical on coal, as it gives a low output for the power it requires.

The *Griffin Mill,* shown in Fig. 9, is somewhat similar to the Fuller-Lehigh Mill in principle. It consists of a steel die against which a roll, also of steel, is made to revolve, and it is between these two that the material is ground. The roll is suspended by a shaft from a spider and actuated by a pulley to which the shaft is attached by a universal joint. The fully-ground material is sucked up and forced through the screens by fans on the shaft, and the coarse particles, falling back into the pan of the mill, are thrown up between the roll and die by means of plows attached to the roll. The finished product passes through the screens and downward between these and the outer casing, through openings in the base, to the screw conveyors. A Griffin Mill will grind from 1½ to 2 tons of coal per hour.

Each mill takes from 25 to 30 H.P. These mills are partly open at the top, and hence are very dusty. The following show about the capacity

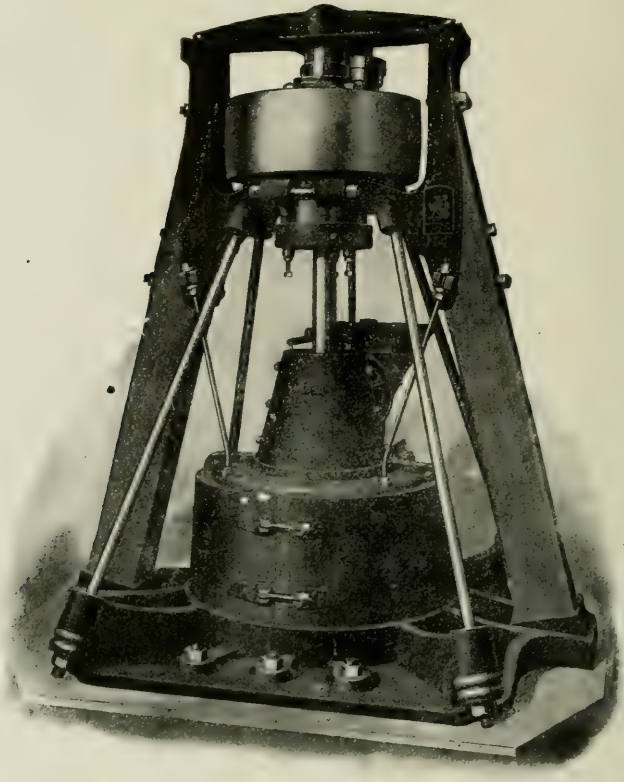


Fig. 9

in pounds of coal ground to a fineness of 92 per cent., passing a No. 100 sieve per H.P. hour:

Fuller Lehigh Mill	200 to 266½ lbs.
Griffin Mill	120 to 160 lbs.
Areo Pulverizer	50 to 66½ lbs.
Tube Mill*	44½ to 66½ lbs.

The *device for burning* the powdered coal is shown in Fig. 10. It consists of an injector through which air is forced by a pressure blower at a pressure of about 0.6 lb. The coal is conveyed out of a

* Including set of rolls necessary to prepare materials for it.

bin by a screw conveyor, falls into the injector, is sucked in and mingles with the air as it passes through the pipe to the furnace. The injector is usually of cast iron, the pipe leading to the furnace is of galvanized iron and terminates in a nozzle of wrought iron pipe, which projects for a foot or more through the hood into the furnace. The screw-conveyor leading from the bin is usually run by a line shaft attached to the fan or the motor driving fans. The connection with

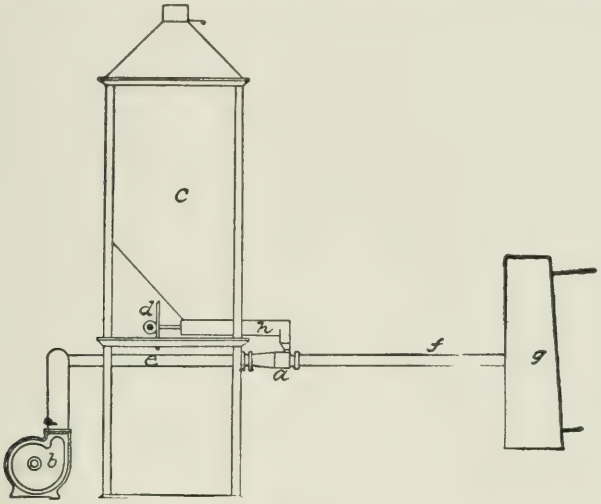


Fig. 10

the shaft is made either by some form of speed controller, or else by a stepped pulley, so that the coal feed can be regulated. The air blown in is usually constant, but may be varied from only a fraction of that needed for combustion to the complete amount. In some cases air from the compressors or high pressure air is used, and in others a combination of the two is sought. The main object in any event is usually to carry the coal into the furnace and to get a good mixture of coal and air, the rest of the air being drawn in by the draft.

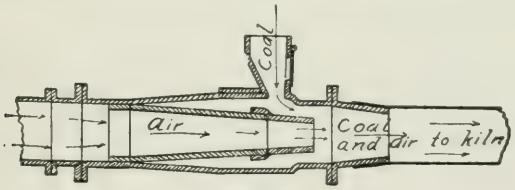


Fig. 11

Fig. 11 shows the construction of an injector for use with low pressure air. The construction of the burner is evident from the drawing. Fig. 12 shows a *compound burner* intended for use with high pressure air. The coal drops down at the three points C, C and C, the air from the compressor enters at H.P.A., and a certain amount of atmospheric air is sucked in at the openings, A.A. As to the relative merits of the two, the low pressure air is much the simpler of the

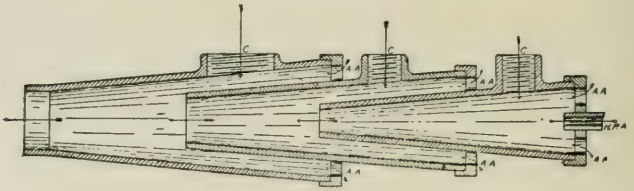


Fig. 12

two where a compressor would have to be installed. With the low pressure system it has been found best to blow into the kiln at least 20 per cent. of the air necessary for combustion with the coal. With the high pressure air, however, only about 5 per cent. of the necessary air is obtained from the compressor. This air is usually delivered to the burner at about 80 lbs. pressure. Now, to burn 100 tons of gas slack per day about 4,000 cu. ft. of low pressure air or 1,000 cu. ft. of high pressure air per minute will be needed. The theoretical horsepower required to supply 4,000 cu. ft. of air at 1 ounce pressure amounts to 1.4 H.P. To compress 1,000 cu. ft. of air to 80 lbs. pressure, 137 H.P. will be required by theory. Hence there is considerable saving in the use of low pressure air.

Mr. Chas. A. Matcham, the designer of the dryer previously referred to, has been granted a patent upon a system of burning which makes use of the natural draft of the furnace to suck the coal in, about 0.4 to 0.6 inch of water draft being needed for this system.

In installing a plant for pulverizing fuel, bins will be needed above the Fuller-Lehigh or the tube mill, but not above the dryer. The coal is carried on a belt or even in barrows or trams from the stock pile or the cars to the pot crusher. From this it may be carried up by a link-belt elevator into the spout leading into the dryer. From the dryer another bucket elevator takes it up into the bin above the Fuller-Lehigh Mill, and a screw conveyor takes the pulverized coal

away from this. Another bucket elevator will be needed to take the coal up to the stock boxes above the burning apparatus. Screw conveyors may also be used to carry the coal either after it leaves the pot crusher or the dryer.

The cost of preparing the coal may be estimated as follows: One ton (2,240 lbs.) of coal will evaporate 15,000 to 16,000 lbs. of water. If the coal contains 6 per cent. moisture it will require 1 ton (2,240 lbs.) of coal to dry 116.6 tons. One attendant will be needed to look after dryer and pot crusher and to assist in shoveling coal when necessary, and one attendant to shovel and keep dryer well fed. One 42-inch mill would have a capacity of about 120 tons per day of 22 hours, and would with pot crusher, dryer and elevator, require about 90 H.P. Basing estimate on above figures, following results are obtained:

COST OF PREPARING 100 TONS OF PULVERIZED COAL.

Drying coal, 1½ tons at $3.00	$4.50	
Attendance, two at $1.75	3.50	
Attendance, two at $1.50	3.00	
		$11.00
Grinding power, 90-H.P., at $40 per year, 350 days	$11.42	
Attendance and supplies	3.00	
Repairs and interest on plant	5.00	
		19.42
Cost per ton, 30.42 cents.		$30.42

COST OF PLANT FOR PREPARING 100 TONS PULVERIZED FUEL PER DAY.

One pot crusher, set	$750.00
One Matcham coal dryer with stack erected	3,000.00
Three elevators	750.00
One 42-inch Fuller-Lehigh Mill, with foundations	3,300.00
One idler	100.00
One bin	300.00
One motor, with wiring, etc.	1,000.00
Shafting, belting, bearings, etc.	1,000.00
Labor erecting	800.00
Building and incidentals	6,000.00
Total	$17,000.00

Add to the above, $4 per foot for 12-inch conveyor leading from fuel mill to furnace, and $500 for each furnace for burning apparatus; storage bin and fans for air.

MODERN ELECTRICAL RESISTANCE PYROMETRY

By

DR. EDWIN F. NORTHRUP

Mr. President, much has been published respecting the scientific aspect of electrical pyrometry. It is not my intent to speak of this side of the subject, nor to describe the details of the construction of electrical resistance pyrometers, as I believe that it will be of greater interest to you if I consider the recent developments of the subject in regard to the practicability and limitations of this class of apparatus for use in the industrial processes. The remarks which I have to make in my paper are along this line.

If at the close of the meeting anyone wishes to ask me any questions regarding the scientific aspect of the subject, I shall be pleased to answer them as fully as I am able.

I wish here to say that the instrument maker is much indebted to The National Bureau of Standard at Washington for obtaining standard pyrometers, by comparison with which others may be calibrated. This Bureau is always most courteous in furnishing full information to instrument makers, or to anyone else who applies for it.

The term pyrometry is most generally and properly applied to the measurement of temperatures above those which can be determined by the mercurial thermometer. While electrical pyrometers are equally suited to the measurement of low, medium and moderately high temperatures, as chemical engineers you will be interested particularly in the reliability and usefulness of these instruments when applied to the measurement of the higher ranges of temperature. The measurement of those very high temperatures, secured by the electric furnace, at which all substances melt or volatilize, can only be made by studying the radiation of light or heat which the highly heated substance emits. This branch of pyrometry, termed radiation pyrometry, makes use of methods and instruments quite distinct from those employed in the measurement of less elevated temperatures. Radiation pyrometry has received much development in the last five years; but the subject is far too extensive to be adequately touched upon on this occasion. The temperature range then, to which I shall refer especially, lies

below the melting point of platinum, and above that where a mercury thermometer may be used.

The question is often asked, "How accurately are temperatures known and reproducible upon the centigrade scale?" As is probably well known to you, all temperature scales are ultimately referred back to the gas thermometer scale. By means of the gas thermometer, the melting points of a series of pure metals of progressively higher melting points are determined. By this means the temperature scale has been fixed and made readily reproducible up to the melting points of the noble metals. Thus the melting point of pure gold has been found by the most recent researches of Arthur L. Day and J. K. Clement, published in "The American Journal of Science," November, 1908, to be 1,060° C., with a plus or minus error not exceeding 1° C. The researches carried out at the N. B. of S. give the most probable melting point of platinum, as 1,753° C. (Bulletin of the Bureau of Standards, Vol. 3, page 208.) The melting point of gold refers to temperatures determined by the constant volume nitrogen gas thermometer. This is reliable in the region of 300° C. to 1,150° C. to $\frac{1}{2}$° C. Knowing the melting points of a series of metals, different types of electrical pyrometers can be calibrated to read directly in degrees of temperature. This is readily done by placing the pyrometer and the metal of known melting point in an electric furnace and noting the scale reading of the pyrometer at the instant the metal fuses. By taking a number of such fixed points, the entire scale can be laid off. This pyrometer then becomes a standard instrument which may be used in the calibration of secondary standards. The manufacturer of pyrometers can obtain calibration curves for his primary standard pyrometers from the National Bureau of Standards. Every measurement of high temperature made in commercial work goes back by several stages to the gas thermometer for its absolute precision. Thus: The reading of the temperature to be measured on the pyrometer used, the adjustment by the maker of this pyrometer in comparison with his standard instrument, the calibration of this standard instrument by comparison with another standard maintained at the National Bureau of Standards, the adjustment of this standard with metals melting at known temperatures, the noting of readings given by transfer pyrometers when these metals melt, the interpretation of the readings of these transfer pyrometers by comparing their readings with the readings of an elaborately constructed constant volume gas thermometer.

An error in the proper and careful carrying out of any of these steps back to the gas thermometer standard, results in a more or less greater inaccuracy in the determination of a temperature in actual degrees. A pyrometer may be exceedingly sensitive to changes in temperature and constant in its performance, and yet give no certain indications of actual temperatures. A pyrometer of this character may be useful in enabling one to repeat temperatures as shown on an arbitrary scale, which have been found by trial to be most suited to a given process.

These relative measurements of temperature have, however, two important disadvantages and limitations over absolute measurements. First, many manufacturing plants have several branches in different sections of the country, each branch making the same product by like processes. If at one branch it is found by trial that the best results are obtained when a particular pyrometer gives certain indications on an arbitrary scale, these results cannot be interpreted so as to be communicated to the other branches of the plant. Thus, each branch must learn by its own experimenting.

Second, if the particular instrument is broken or goes out of calibration, the whole process of experimentation must be repeated with a new instrument or scale having a different constant. This seemingly obvious consideration shows the great desirability of having pyrometers read accurately in actual degrees Centigrade or Fahrenheit and not merely scale divisions which are relatively correct but not capable of being interpreted in actual temperature degrees.

As all physical states vary with temperature, it is easily concluded that few chemical and manufacturing processes are entirely independent of temperature changes. In many the value of the product is dependent in a most delicate manner upon temperature control.

The necessity of judging temperatures is generally recognized by superintendents, foremen and laborers. The foremen, however, are generaly sure that they have trained their eyes to judge temperature quite accurately enough for the purpose. One of these men with a "trained eye" in a ship building yard was tested by the speaker on his ability to judge the temperatures of a large annealing furnace. A reliable pyrometer showed his guess to be off by about 200° C. The condition of the light, retinal fatigue, and imperfect memory, all influence one's estimate of high temperature to a degree that renders such estimates practically valueless for processes requiring close control. A poor pyrometer is better than most estimation, and an accu-

rate one is far better than any human judgment though based on years of experience.

The average foreman and superintendent is perhaps willing to admit that if the instrument is accurate it is better than judging temperatures, *while it is in order*. But, they say, pyrometers, are too complicated, too delicate, and wholly unreliable. It is the prevalence of this opinion that prevents high temperatures being measured as constantly and nearly as precisely as ordinary temperatures are measured by the mercury thermometer. Our feelings tell us what to do when ordinary temperatures get too high or too low, but no such monitor guides us when iron and glass annealing temperatures vary so as to ruin our product. It is more important to the industries and the wealth of the country to measure high temperatures with precision than are all the measurements which are made with the mercury thermometer.

Why then are these pyrometers unreliable? To answer this, I will first briefly mention the features which are essential to pyrometer installations in commercial plants. Whether we have in mind, electrical pyrometers of the thermo-couple type, or electrical resistance pyrometers, both of which take the temperature in one or more places and indicate or record it in another place, there are the "bulbs" located at the points whose temperature are desired, the indicator with which the temperature of the bulbs is read, and the system of wires which join the bulbs to the indicator. The bulbs, so to speak, are the finger tips that feel the temperatures and the wires are the nerves that put these into communication with the interpreting indicator—the brain. Defects in the bulbs, or the indicator, give false temperatures, and defects, such as opens, crosses, grounds, and leaks on the connecting wires stop or falsify the communication between bulbs and indicator.

Electrical pyrometers are unreliable then for reasons such as these: The working of the teletemperature system, depends upon principles and a force which the operators of furnaces, chemical plants and the various manufacturing processes, know nothing or little about. Hence if the most minute element of the transmission system fails to work, as it should, the electrically untrained man in charge is baffled in making a repair which the expert would effect in a moment. Thus, a pyrometer system, of two dozen pyrometers reading upon a single indicator, may fail to work utterly in the midst of an important and costly process. The simple cause may be that a wire becomes corroded on its surface where it is clamped by a binding post, resulting in a

high resistance or open circuit. Again, by the principles upon which electrical pyrometers necessarily depend, the energy which is available to move the indicating needle over its scale, or the pen of a recorder over its record sheet, from the standpoint of the mechanical engineer, is microscopically small. The foreman of a blast furnace could as easily thread a No. 120 cotton thread through the eye of a No. 10 needle while watching the pouring of a furnace, as to try to level and adjust the wavering needle of a delicate galvanometer, upon the indications of which depend the temperature, and perhaps the value, by thousands of dollars, of a run of pig iron. A galvanometer needle, steady and smoothly moving in the manufacturer's laboratory of reinforced concrete, is often an uncertain and dancing imp when located beside an annealing oven with a trip hammer near by; and it may have to be read through a glass cover upon which has settled a nearly opaque covering of fine foundry dust.

Another cause of unreliability rests not with the situation, the intelligence of the workmen, or the flimsy character of the wiring, but with the improper construction and the inaccurate calibration made by the maker of the bulbs or fire ends, and the indicator. But even if the pyrometer outfit has been faithfully and properly constructed, the best pyrometers may become unknowingly inaccurate or ruined by exposures to a temperature far beyond that for which they were constructed.

In view of facts like these, of which the above are but a tithe of the causes of unreliability that may arise, it is not to be wondered at that despite the great necessity of measuring high temperatures, electrical pyrometers are discarded over and over again, by hard headed manufacturers as too unreliable to use and to trust. They prefer to rely upon the estimations of temperatures which experience makes seemingly accurate. Must we rest with this conclusion, or can pyrometers be made reliable? We believe they can, and this belief is confirmed not alone by study of the subject, but by an observance of many successfully operated installations.

The laws of electricity and what it will do under given conditions are as certain and as well understood as are the laws of mechanics and thermodynamics. The electrical principles upon which pyrometers operate are sound and theoretically perfect. The realization then of these principles in reliable and continuously operative pyrometer installations under existing conditions of practice is an engineering and not a scientific problem. This engineering problem is divided be-

tween the manufacturer of the apparatus who must correctly design, construct, and calibrate the pyrometers and their accessories, and the users of the pyrometers, who must adopt methods, under advice, for their substantial installation and intelligent maintenance.

As the energy to move the pointer of the indicator is small in any case, the manufacturer makes use, where the temperatures will permit, of that form of pyrometer which utilizes the most energy. In this respect, the resistance pyrometer is incomparably superior to the thermo-couple. The pure metals, as copper, nickel, and platinum, increase in their electrical resistance in a perfectly regular way with increase in temperature. This increase is very considerable.

One ohm of resistance material increases to about 1.04 ohms when the temperature increases by 10° C. It is also found, by long experience, that properly treated, pure metals always return to the same resistance when brought back to the same temperature, hence the availability of these metals for measuring temperatures. The resistance thermometer unlike the thermo-couple, develops no energy itself when raised in temperature. The resistance is determined by some one of the many well known methods for determining resistance, but in all of these the energy which moves the needle over the scale of the indicator comes from a battery which supplies current to the system. The more battery power the more energy is available for moving the pointer, and the energy which can thus be used in practice is quite considerable.

The resistance thermometer has its limitation in the measurement of high temperatures at a temperature around 1,200° C. Above this temperature, the platium wire used slowly volatilizes producing a slow but continuous increase in the resistance at a given temperature of the resistance wire. Below this temperature down to that of liquid air the resistance thermometer is, in the speaker's judgment, more accurate, more reliable, and capable of utilizing more energy than the thermo-couple. Above 1,200° C. and below 1,600° C. the platinum plus 10 per cent. rhodium thermo-couple will take its place.

The indicator and the resistance thermometer bulb have been worked out by the manufacturer until they are no longer fragile, inconstant, or unreliable. But, however well these may be constructed, electrical resistance pyrometers will continue to be unreliable unless the wiring system is properly installed and properly cared for. I dwell at length on this subject because the engineering solution of the problem of high temperature measurement has reached a point

where proper installation and maintenance is alone all that remains to make successful and entirely reliable the apparatus which is used. If a mechanical engineer wishes to transmit ten horse power across a factory, he puts up in a substantial manner a line of shafting and it stays in order. An electrical engineer could carry the same power across the factory with a single wire the diameter of a pin laid on the floor. He can thus with slight effort get his result at once and the temptation is great to put up flimsy uncertain wiring, but such transmissions are short lived, and it is then indeed invidious to say, as I have often heard said, that electrical installations cannot be relied upon like mechanical installations. If the ten horse power were carried in a lead incased cable, as substantially supported as the shafting, and as carefully connected to generator and motor at its ends as is the shafting, the electrical transmission would remain in operation when a line of shafting and belts had rusted and rotted into uselessness.

The conclusion of this is that electrical resistance pyrometers are not only capable of being very accurate within two to five degrees at 1,200° C., but can be made entirely reliable, if installed with the same care that is put upon important mechanical installations. As the methods worked out for such proper installation are the business of experts in pyrometer work, no plant should be installed without following wiring diagrams and full instructions given by such experts. If this is done the systems will not be unreliable, they will not fail, and manufacturers will gladly make guarantees of perfect operation for a year or more.

There is such great variety in the processes, chemical and manufacturing, which require temperature measurements, the diversity of conditions to be met is so extreme, and the places in which temperatures are taken differ so widely in character, that no fixed design of pyrometer is equally well adapted or adaptable to all.

It is generally more or less of an engineering problem to select from the various forms and designs of pyrometers, which are available, that particular type which is best adapted to any particular case. Under temperatures of 1,200° C. some form of the resistance pyrometer is generally most suitable. But these vary in many respects, the most important one being the kind of protecting case which must be used so that the pyrometer will be accurate and quickly assume its temperature, and yet be so protected as not to be easily injured or destroyed by rough usage or handling. Thus a pyrometer merely encased

in a porcelain tube might serve well if permanently inserted in flue gas, but be useless for taking the temperature of molten lead in kettles. The design of the proper type of pyrometer is the business of the manufacturer, and he can always work out this problem, where a solution is possible, provided he is fully informed by a prospective buyer of the precise conditions to be met and the nature of the place in which the pyrometer is to be inserted. Prospective purchasers cannot be urged too strongly, for their own interest, to furnish sufficient information to the manufacturer of pyrometers to enable him to give adequate advice on the best solution of the engineering problem to be met.

The pyrometers themselves, however, form but a part of an installation. At some selected observation point, the temperatures taken by the pyrometers must be observed. The observation of the temperatures taken by any number of pyrometers, by means of a suitable multiple point switch, can be made in succession upon a single indicator or automatic register. Two indicators, or recorders, located at different points in a building, can also give simultaneously the temperature registered by a single pyrometer. Thus a workman at the furnace, and a superintendent in the office at the same time can observe the temperature given by the same thermometer. It must rest with the prospective user of an electrical pyrometer installation to decide at what point or points, and in what manner, and what ranges of temperature he wishes to observe. The science of electrical resistance pyrometry has developed to such an extent that he has much to choose from.

In the first place, without any error due to the resistance of the wires leading to the pyrometers he can have them as distant from the observation point, and as widely separated as he chooses. The number of the pyrometers installed may be indefinitely enlarged as they can all be furnished to read from the same indicator, and are entirely interchangeable.

Secondly, at the observation point the temperatures can be taken upon a so called dial indicator by the manual manipulation of a handle until a galvanometer needle shows a balance, or they can be read directly from the deflection of an instrument in all external respects like a switchboard voltmeter, but having a scale marked in degrees of temperature instead of volts.

Lastly, the temperatures, whether taken with a resistance pyrometer or with other forms, can be automatically registered in the form of a continuous ink line drawn upon a long strip of paper. Such a

self registering instrument may be termed an autographic temperature recorder to distinguish it from one arranged for giving a like result by means of a line traced on sensitized paper by a photographic process.

An autographic recorder of temperature of great sensitiveness and high accuracy operating with the resistance type of pyrometer is now fully developed, and possesses among others these important features: The record sheet is laid off in rectangular coördinates. The record may therefore be planimetered and so give mean temperatures. The width of the sheet is ten inches standard, but may be made greater or less if demanded. The time ordinates may be expanded or contracted as desired by changing the speed of the clock feed from 3 inches per hour to a lesser amount. The sensitiveness of the apparatus is such that the ten-inch interval may be made to correspond to only 4° C. and as the accuracy of the registration is better than $\frac{1}{2}$ per cent., temperature variations as small as .02° C. can be recorded. The temperature interval for the ten inches may, however, be made as great as desired, and when greater than 100° C., an accuracy of $\frac{1}{4}$ per cent. may be regularly obtained. Thus temperatures extending over 1,000° range may be autographically recorded to within two and one half degrees.

The criticism that pyrometers are unreliable may be launched with greater force against automatic apparatus intended to record the indications of pyrometers. This criticism is difficult to meet, yet the attempt has been made, because the unbiased evidence of an automatic continuous record of a temperature run in an important process is greatly to be desired. The simplicity in the construction, the complete and easy interchangeability of all the parts of the most recent recorder of this character, gives that certainty of a continuous performance which we trust entitles it to be called reliable.

This instrument and the two of the types of indicators mentioned are open to your inspection. The limit of time upon this occasion necessitates, that the subject of resistance pyrometers be touched upon only in its broadest generalities, and hence, I have omitted all mention of structural details. A brief list may be given before closing of some installations of resistance thermometers and pyrometers which will present to your minds a very small part of the extensive applicability of this branch of the ever widening science of electricity.

In connection with the recent building of railroad tunnels under harbors and rivers, the Pennsylvania Railroad carried out an engineering experiment of great magnitude. At the foot of East 35th street,

New York, a tunnel of small diameter was run underneath a part of the East River. By means of pipes laid in this tunnel brine at about 35¼ C. was circulated for months in the tunnel. Its low temperature abstracted the heat from the walls of the small tunnel, freezing in cylindrical zones the silty soil. The frozen material thus formed a hard self supporting mass which would permit the enlargement of the small pilot tunnel to its full required diameter. The progress of the freezing was observed by hundreds of resistance thermometers located in the soil at varying distances from the axis of the tunnel. The difference in temperatures of the entering and leaving brine—a difference of less than 4° C.—was registered to an accuracy of .01 C. by means of resistance thermometers and their registrations were photographically recorded, without interruption for months. The measurements of temperature by means of electrical resistance thermometers in this experiment were entirely successful and accordant.

At the U. S. Capitol at Washington, the office of Mr. Woods, Superintendent and Supervising Architect, is located in the basement some 500 feet from the Senate Chamber. Our senators, easily chilled and heated, demand a close regulation of temperature in all parts of the hall. Mr. Woods, with almost seeming magic, notes when seated in his office, the temperature within an accuracy of ¼° Fahr. of any one of 24 points in the Senate chamber, as well as that of the air which enters and leaves it. This performance is made easily possible by an installation, carefully wired, of nickel wire resistance thermometers.

Cars loaded with grain, corn or wheat, start from Chicago with sound grain, but often arrive at their destination with the grain heated and sprouting. The rise of temperature will begin at a point in the interior of the moist grain and rapidly spread to the entire car. To study and guard against such destructive rise in temperature of grain, agents of the government have employed resistance thermometers embedded in the grain, usually three bulbs in each car. At suitable intervals, a temperature indicator is attached to the exposed terminals of wires, leading to the buried thermometers and the temperature of the point where they are located is read. All of the thermometers being exactly alike, the dial of the indicator is laid off in degrees and reads the temperature directly and with greater precision than a mercury thermometer could give.

By a method precisely similar, the U. S. Weather Bureau determines the temperature of the soil at various depths. Many resistance

thermometers are in use for this purpose. A Government experiment station has even employed the resistance thermometer to measure the temperature of a hen's egg, while the hen is sitting upon it, at different stages of its hatching process. The knowledge gained helps in the proper regulation of the temperature of incubators.

In one of the buildings where photographic films are made and dried, and where no white light may be used to read mercury thermometers, temperatures with wet and dry bulbs are read at over 75 points by means of a single dial indicator in the office.

In records of the temperature of the air, the resistance thermometer is incomparably more sensitive and quick acting than the mercury thermometer, and is now serving at Mount Weather Experiment Station in Virginia to study the rapid small fluctuations of temperature, which when automatically recorded, are seen to be generally going on.

The cases above mentioned, though belonging to resistance thermometry, or the measurement of medium temperatures, have been outlined to merely indicate the diversity and flexibility of this mode of temperature measurement. Speaking more strictly of resistance pyrometery, or the measurement of high temperatures by means of the resistance pyrometer we may mention the few following typical installations.

A company in this city manufacturing lead covered telephone cables, measures, with platinum resistance thermometers the varying temperature of the lead in the large lead kettles. This must not get too hot and burn the insulation nor too cold to flow well.

The New York Ship Building Company employs resistance thermometers to indicate the temperature of large steel annealing furnaces, which temperature it is important to control.

The pyrometers are incased in long nickel tubes and are roughly handled without injury by ordinary workmen. A furnace superintendent reads on the direct reading indicator his temperature to a precision of about 5 to 10 degrees. It is in glass annealing ovens and leers that the resistance pyrometer finds itself in most congenial temperatures, and renders a most valuable record. If the glass in the ovens gets too hot it melts. If it gets too cool, it cracks in customers' hands and complaints and replacements or loss of business occur. In a typical installation in a large glass works, several pyrometers are permanently installed in the ovens and leers. A deflection type indicator, which by turning a single handle is switched upon any pyrometer,

tells the foreman how his heat is running. A dial indicator in the superintendent's office enables the temperatures of the same pyrometers to be read there at the same time, and an autographic recorder may be switched upon any oven and give the history of its temperature run in the form of a perfect ink record. This is drawn upon a long sheet of cross section paper, ten inches wide, which may be cut up into lengths of 6 feet, each representing runs of 24 hours, and filed for future reference.

In the contact process of the manufacture of sulphuric acid nicety of temperature control and hence precision of temperature measurement appears to be an important consideration in order to obtain the maximum efficiency. Many pyrometers of the resistance type are now installed and indicating temperatures to an absolute accuracy in the neighborhood of 1° C. over half way up to a 1,000° C. The sensitiveness of these thermometers is such that temperature changes of a .01° C. can be detected.

In closing it may be said; the theory of resistance pyrometers is fully developed and shows the possibility of rigidly accurate results being obtained; the engineering details have been developed so that all temperatures from that of liquid air to 1,200° C. may be both accurately indicated and recorded, and lastly, these results can be actually obtained in practice and indeed are now obtained, with installations which are reliable in defiance of the prevalent opinion to the contrary. But to make the last statement true, intelligence of a good order must be used all along the line from the manufacturing and calibrating of the instruments to their adequate and proper installation. If intelligence is used thus far, very ordinary persons can use the instruments and understand their indications. Though even here in the case of large installations of many pyrometers, it is of doubtful commercial economy not to employ with suitable recompense, trained persons who are fully capable of using apparatus which is so difficult to render entirely "fool proof."

Discussion.

Mr. Booth: "When used for flue gas analysis what would such a pyrometer cost?"

Dr. Northrup: "I hardly think that is a proper question for one in my position to answer at a scientific meeting of this kind. I ask to be excused."

President Sadtler: "I think, however, that if any of you go to him personally you will get the information you want."

DR. MCKENNA: "I should like to ask Dr. Northrup about the application of pyrometers in large kilns. Is there any special construction required for their use in these places?"

DR. NORTHRUP: "In ceramic kilns the temperatures reach a point where the glaze runs. 1,100° C. is it not? Pretty high temperatures. A resistance pyrometer capable of measuring this temperature should have, like any other piece of apparatus, a considerable factor of safety. If the temperatures to be measured regularly reach a point as high as the thermometers are constructed to measure, it is hardly safe to recommend them. I am not sufficiently informed as to the exact temperatures at which kilns run to answer definitely whether resistance thermometers are suitable for this work. If the temperatures of the kilns at any time exceed 1,200° C., not going beyond 1,600° C., the temperature might be measured with thermo-couples of the platinum platinum-rhodium type."

DR. MCKENNA: "I know it is quite suitable in some of the kilns. I thought perhaps there was some special construction for the thermometers or something in the manner in which they are located."

A MEMBER: "I should like to know whether the limit set to temperature measurement with the resistance thermometers, is determined by the constancy of the resistance of the wire and if it is possible to increase the temperature limit by alloying the wire or by selecting other kinds of wire."

DR. NORTHRUP: "Some hope has been held out of raising the limit of temperature of resistance thermometers by using iridium instead of platinum wire but the researches of Dr. Day, in Washington, show that iridium is much less reliable than platinum, as iridium begins to volatilize at lower temperatures than platinum and is consequently less constant than platinum. As a result of all the researches to date platinum appears to meet the requirements better than any other metal that has been tried. The resistance of all the pure metals, silver, copper, nickel, gold, platinum and the like, increases with fair uniformity with the temperature. For temperatures below 300°, nickel is quite as suitable to use as platinum, having a high specific resistance and being much cheaper than platinum. Above 300° C. the most suitable metal, as before stated, is platinum."

PRESIDENT SADTLER: "Then it is wrong to suppose, as a great many people do who are not particularly informed about it, that there is a better metal to use than platinum?"

DR. NORTHRUP: "There is no better metal to use than platinum.

Iridium is not suitable as Dr. Day has shown that this metal volatilizes."

SECRETARY OLSEN: "How accurate is the temperature scale known, say up to 1,000° or 2,000°? What would you give as the limit of error?"

DR. NORTHRUP: "The accuracy of the constant volume gas thermometer scale is within $\frac{1}{2}$° C. at about 1,000°. The gas scale can scarcely be reproduced to quite that accuracy outside of the laboratory where the scale is determined. The vehicle, so to speak, with which the scale is carried about, is a series of fixed melting points of certain metals. These metals having certain specifications for purity may be purchased in the market. The melting points of these metals when determined by direct comparison with the gas scale can be used to reproduce the scale to within perhaps 1° at 1,000° C. The question of accuracy in respect to the absolute temperature being measured and the question of sensitiveness of the apparatus, thermo-couples or resistance thermometers, which measure the temperatures, are of an entirely different character. As far as sensitiveness is concerned, variations in temperatures of .01° C. are easily measured. This sensitiveness may be obtained with either resistance thermometers or thermo-couples. If thermo-couples are used for precision work, the electro-motive force which is developed should be measured with a potentiometer and when thus used they are susceptible of giving as great accuracy as the resistance thermometer. Thermo-couples used in this manner are calibrated by determining the electro-motive force which is developed when at known different temperatures, as given by the melting points of a series of metals, these melting points of the metals having been previously ascertained by reference to the gas scale. As the gas scale only reads up to a little over 1,000°, temperatures which are measured by thermo-couples up to 1,600$\frac{1}{2}$ are based upon an exterpolation of a curve giving the relation between temperature and the thermo-electro-motive force of a thermo-couple."

SECRETARY OLSEN: "Then you do not know what 1,600° is equal to?"

DR. NORTHRUP: "The law that a thermo-couple is obeying is determined by the gas thermometer in the range over which the gas thermometer can be used. Then by exterpolation of the curve the thermo-couples are assumed to give correct indications up to 1,600°.

I would invite those interested in these matters to refer to recent publications in the bulletins of the Bureau of Standards, by Dr. Waidner."

CHEMICAL SPECIFICATIONS FOR SULPHITE PULP

By
J. A. DE CEW

Owing to the variety of woods that are now used in the manufacture of sulphite cellulose, as well as the different chemical and physical treatments which the material undergoes in the process, there is a considerable variation in the character and quality of the sulphite fibres that may be found in the open market. The suitability of a certain sulphite for a particular class of paper, is generally determined by mill trials in which a large amount of material is involved in the experiment, so that this method often results in some very expensive information.

It is therefore desirable for the promotion of accuracy in the selection of a suitable sulphite fibre for paper manufacture, that the characteristics which differentiate the various sulphite stocks, should be definitely recognized and agreed upon by the paper and pulp chemists.

In order to further develop the scientific treatment of this subject, some distinctive chemical conditions are herewith referred to, which may serve as a basis for the preparation of suitable specifications for exact requirements.

In the isolation of the sulphite fibre, by the resolution of the lignified portion of the wood, some of the less resistant celluloses have entered solution, while a portion of the more resistant ligno-celluloses remain associated with the fibre. To remove the latter and purify the cellulose, bleaching agents are used, and when but a small amount of these are required, the fibre is classified as an easy bleaching pulp. The relationship between the amounts of bleaching powder required for the production of a No. 1 White, is already an established basis of comparison for the grading of cellulose materials which require to be bleached.

For most classes of paper but especially those which are made from unbleached fibre, the structure of the individual fibres and their ultimate strength are characteristics of great importance. Under the microscope some fibres can be seen to be on the point of breaking,

others in fragments and others quite sound. Many broken fibres will indicate a brittle condition in the entire fibre, which might have been caused by severe thermal treatment or the formation of hydro-cellulose by free sulphuric acid in the cooking liquors. Perhaps this latter point has not been proved, but it is a reasonable supposition. May there not be a relationship between the amount of hydro-cellulose in the fibre and the ultimate strength, and would the percentage of cellulose dust in the fibre be a means of grading or classifying the stock?

Without doubt, when strength in fibre is a requisite, a standardized sieve test would give some very valuable results, for a strong flexible fibre carries very little dust.

An ideal fibre is one that is not only strong, but is also easy to bleach and size. These characteristics are seldom combined except in the most carefully prepared stocks, for one pulp may bleach easily and yet be very difficult to size, on account of the presence of inorganic impurities which are quite injurious to the sizing agents. Sulphites have been known to contain an ash as high as 1.5 per cent., and of this about one per cent. was sulphate of calcium. Owing to the presence of this calcium salt precipitated from the cooking liquors, the water became very hard in the beating engine, and as soon as the size was added, calcium resinates were formed, with the result that very little sizing effect was obtained.

The percentage of ash therefore has a direct bearing upon the ease or difficulty, with which a sulphite may be sized, and when it is necessary to make a hard sized paper, the amount of ash in the fibre should be as low as possible, and preferably under 0.5 per cent.

A difficulty that is often caused by certain sulphite stocks, is the accumulation of a dark pitchy matter upon the felts and rolls of the paper machine. This pitchy material comes from fibre which is made from woods of a more resinous character than usual, such as balsam, tamarac or pine.

The resin in the pores of the wood, being insoluble in the acid liquors used, remains in the fibre, and may be recognized microscopically either imbedded in the pits or unattached. When the resin content of the fibre is 5 per cent. or over, the unattached resin particles begin to stick to the press rolls and accumulate in the form of pitchy lumps. The percentage of resin in the fibre, is therefore a fairly good indication of the kind or quality of wood used in the process of manufacture, the amount being greater when balsam, jack pine, or inferior grades of spruce are used.

Some of the chemical determinations that may be applied to sulphite fibres, may be epitomized as follows:

1. The amount of lignocellulose material present, in terms of the amount of bleach required to destroy it.

2. The percentage of ash and the amount of sulphates it contains.

3. The percentage of resinous matter, determined by extraction.

4. The percentage of dust, consisting of cellulose fragments, separated by sorting with a sieve.

From these tests it is quite possible to determine the general characteristics of a fibre, and its suitability for the purpose for which it is required.

The following limitations for the specifications for sulphite pulp are suggested:

Bleaching sulphite—That which will bleach to No. 1 permanent white with under 20 per cent. of 35 per cent. bleaching powder.

Easy bleaching—Under 16 per cent. bleaching powder for same shade as above.

Very easy bleaching—No. 1 white, with under 12 per cent. bleach.

Ash and sulphates—

Quality, A1, sulphite—must not show the presence of sulphates and have a total ash of under 0.4 per cent. of the bone dry weight.

Quality, 1, sulphite—Must not contain over 0.75 per cent. of total ash. Quality No. 1 must also not contain over 0.2 per cent. of sulphates and sulphites calculated as SO_3

Resin—

Quality, A1—Under 0.5 per cent. total resinous matter by ether extraction.

Quality, 1—Under 0.7 per cent. total resinous matter.

Strength of fibre as judged from the dust and broken fibres.

The writer has not yet perfected a test on this work as it requires much more investigation, and we have yet to choose between a dry method and a wet method for separating the fine from the perfect fibre.

A definite method for grading the strength of fibre is very badly needed however, and I should be glad to have the coöperation of any of our members who are interested in this work.

PURITY OF COMMERCIAL LIQUEFIED AMMONIA GAS AND APPARATI FOR TESTING IT

By

DR. F. W. FRERICHS.

I present for your inspection two forms of apparatus which are used for testing liquefied ammonia gas. These apparati are the result of a number of improvements made in the course of twenty-five years on less perfect devices. In order to explain their superior efficiency, I will show you the older forms of apparati from which they have been developed.

The test is based upon the low boiling point of liquefied ammonia gas, which is 28° F. below zero, and upon the consideration that the impurities which are likely to be present have a much higher boiling point. Therefore, if a sample of liquid ammonia be evaporated, the impurities contained in same would probably remain in the vessel and their quantity could be ascertained. Liquefied ammonia gas now is considered good by American ice manufacturers if no visible residue is left in a flask in which a 4-oz. sample has been evaporated.

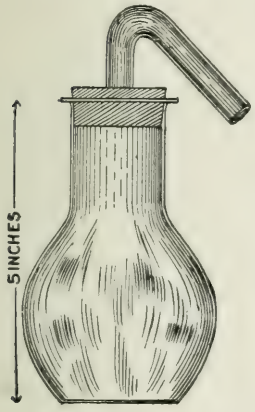


Fig. 1

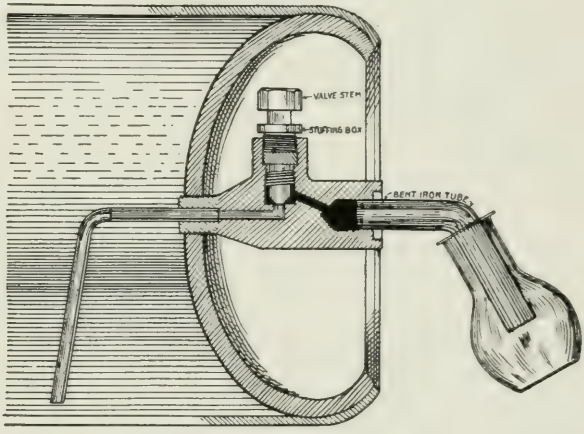


Fig. 2

Figure 1 shows a test bottle similar to the one in common use in the United States, and Figure 2 shows the mode of drawing a sample from a cylinder of ammonia.

This mode of testing gives only approximate results. One source of error is the moisture contained in the surrounding atmosphere. On account of the rapid evaporation of the liquid ammonia, the iron tube by which the sample is drawn becomes very cold, and so does the flask, and moisture from the air will readily condense upon the cold surfaces. By drawing the sample quickly and closing the flask at once with a perforated cork carrying a bent glass tube, contamination of the sample with moisture is prevented as much as possible, but never entirely. But the fundamental source of error in this method of testing rests in the fact that small quantities of the impurities often contained in the commercial ammonia will evaporate with the ammonia used for the sample, on account of which fact the evaporation test gives results which are too low.

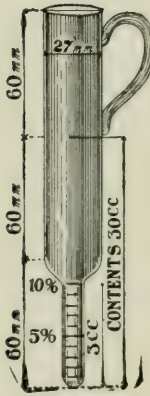


Fig. 3

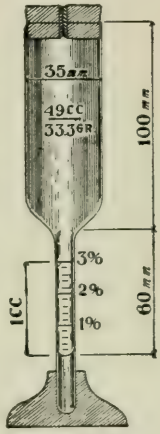


Fig. 4

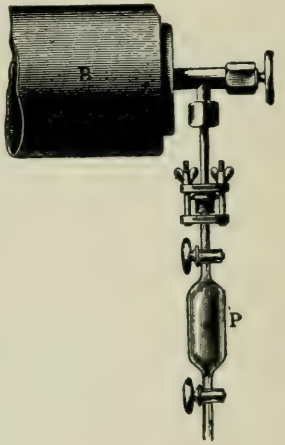


Fig. 5

Fig. 6

While this method of testing had become customary in the United States, the Linde method was used in Europe. The apparatus shown by Figure 3 is used for the Linde test,* and consists of a wider tube with a small hole near the center, the tube being drawn out at one end into a smaller tube, which is closed at the bottom. The graduation is as indicated in the picture. In making the test the tube was supposed to be filled to the opening in the center and the sample was permitted to evaporate in the open air. In operating this apparatus it would frequently occur that the ammonia would foam and boil up

*Zeit. f. Angew. Ch. 1897, p. 224.

and part of the sample would run out of the opening. Since the time of evaporation was directed to be about three hours, the open vessel would permit much moisture to be attracted from the air. Besides the graduation was incorrect, because it did not take into consideration the difference in the specific gravities of the liquid ammonia and of the residue left upon evaporation. For these reasons the results could not be accurate, but the degree of purity expected by European ice makers was not very great, an article leaving, upon evaporation, 1 per cent. of liquid residue, being quite acceptable to them. (See Lunge on Coal Tar and Ammonia, 4th German Edition, Pg. 161.)

Lange and Hertz improved upon this apparatus and changed it to the form shown by Figure 4, the description of which was published in 1897.* They omitted the overflow hole and replaced it by a mark indicating 49 c.c. = 33.3 gr. ammonia. They increased the size of the sample from 30 c.c. to 49 c.c. and narrowed the tail end in order to permit a larger graduation. The latter they made proportionate to the specific gravities of the fluids to be measured. Finally they closed the tube with a cork during the time of evaporation, which was about three hours, letting the ammonia vapors escape through a narrow notch in the stopper. The result of tests made with this apparatus seemed to be sufficiently correct, since they worked with liquefied ammonia gas, leaving, upon evaporation, about 1 per cent. of non-volatile liquid residue. They also reported upon the quality of several German makes, finding that the average commercial article left upon evaporation about 1 per cent. of an oily residue. The nature of this residue, of which they secured 185 c.c. by evaporating 19.5 kilograms of commercial liquid ammonia, was analyzed, and ethylic alcohol, acetonitril and pyridine were found in large quantities, while the presence of smaller amounts of benzol, naphthaline and carbonate of ammonium and also of lubricating oil could be established.

Since it was evident that both the Linde and the Lange and Hertz test would show upon evaporation more residue than the ammonia really contained, the Actiengesellschaft fur Chemische Industrie in Mannheim caused Bunte and Eitner to design a new method, which they published in 1897.† Their apparatus is represented in Figure 5, and consists of a pipette having a strong glass body and a stop-cock on each end. The sample was drawn under pressure, and its weight was ascertained. The pipette was then put in an upright

*Zeit. f. Angew. Ch. 1897, p. 224.
†Jour. f. Gasbeleuchtung. 1897, 174.

position, the upper end was connected with three caustic potash drying tubes, and by opening the upper stop-cock the sample was permitted to evaporate. After evaporation, the pipette containing the residue was heated in an air-bath to 70°-80° C., subjected to a current of air at that temperature and the weight of the residue was ascertained.

It is evident that this method favored the seller, since it generally would show a good test, the current of air carrying most of the residue out of the apparatus.

K. Urban* has improved upon this method, using an apparatus represented by Figure 6. He graduated his pipette and heated the residue only to 30° C. to expel ammonia, but he did not use a current of air, nor did he use caustic potash tubes. The specific gravity of the residue he determined by reading the volume on the graduation and ascertaining the weight. But he makes an error by not considering the difference of specific gravities of air and ammonia gas, which was for his apparatus about 30 milligrams. Urban compared his method with other methods of testing then in use, and tabulated his results as shown in Table 1.

TABLE NO. 1.

A.—BY URBAN'S METHOD.

43 c.c. = 26.5 gr. NH_3 left 0.25 gr. = 0.94% Residue
43 c.c = 26.5 gr. NH_3 left 0.25 gr. = 0.94% Residue
45 c.c. = 27.7 gr. NH_3 left 0.25 gr. = 0.91% Residue

B.—BY LINDE'S METHOD.

30 c.c. = 20.4 gr. NH_3 left 0.534 gr. = 2.61% Residue
30 c.c. = 20.4 gr. NH_3 left 0.530 gr. = 2.59% Residue
30 c.c. = 20.4 gr. NH_3 left 0.535 gr. = 2.62% Residue

C.—BY THE LANGE AND HERTZ METHOD.

50 c.c. = 34 gr. NH_3 left 0.45 gr. = 1.32% Residue
50 c.c. = 34 gr. NH_3 left 0.46 gr. = 1.35% Residue
50 c.c. = 34 gr. NH_3 left 0.45 gr. = 1.32% Residue
50 c.c. = 34 gr. NH_3 left 0.51 gr. = 1.50% Residue
50 c.c. = 34 gr. NH_3 left 0.50 gr. = 1.47% Residue

The last publication upon this subject has been by Lange and Heffter in 1898,† who reject the Linde method as being incorrect, and prove that the Bunte-Eitner method is unreliable, since its results are always too low. Then they compare the Urban and the Lange-Hertz methods and prove by a number of experiments on samples of liquid ammonia containing known quantities of benzol, alcohol, pyri-

*Chem. Ztg. 1897. 720.
†Die Chem. Industrie. 1898, 2.

dine, acetonitril and also of mixtures of either two of these in equal parts, that Urban's method always gives too low results, while Lange-Hertz's method produces too high figures. In making the investigation they have operated with liquid ammonia leaving 0.2 per cent. residue upon evaporation, this being the best commercial ammonia which they could obtain. The results of their experiments are compiled in Table 2.

TABLE No. 2.

Kind and Quantity of Addition Present.	%	Found by Urban's Method. %	Found by Lange-Hertz. %	Found Per Cent. of Total Present by Urban. %	Found Per Cent. of Total Present by Lange-Hertz. %
Benzol	1.5	0.99	1.7	66	113
Benzol	1.5	0.75	1.5	50	100
Benzol	1.5	1.13	1.5	75	100
Benzol	1.5	0.77	1.0	51	67
Benzol	1.5	0.76	1.0	51	67
Pyridine	1.0	0.65	1.2	65	120
Pyridine	1.0	0.70	1.1	70	110
Water	1.1	0.91	1.2	83	109
Alcohol	1.0	0.80	1.6	80	160
Alcohol	1.0	0.79	1.8	79	180
Alcohol and Acetonitril	1.0	0.79	1.5	79	150
Alcohol and Benzol	1.3	0.79	1.4	61	108
Alcohol and Benzol	1.3	0.66	1.5	51	115
Alcohol and Pyridine	1.0	1.01	1.5	101	150
Alcohol and Pyridine	1.0	1.02	1.6	102	160
Benzol and Pyridine	1.0	0.80	0.9	80	90
Benzol and Pyridine	1.0	0.66	1.1	66	110

They conclude that in Urban's method part of the impurities evaporate with the ammonia, and prove this theory by leading the vapors of 20 grams of ammonia through a tube filled with pumicestone and cooled to —30°C., whereby the tube increased in weight by 26 milligrams.

They found that the amount of foreign substances evaporated with the ammonia varied with the nature of the substances. Benzol and pyridine escaped easily, alcohol and water more difficult. A mixture of alcohol and pyridine in equal parts did not seem to evaporate with the ammonia. However, with this statement I cannot agree. I have repeated this series of tests and the results are compiled in Table 3. My figures show that a mixture of pyridine and alcohol evaporates

TABLE NO. 3.

Liquid NH_3	Addition Present		Addition Evaporated by Urban.	by Frerichs.
Grams.	Kind.	Grams.	%	%
98.5	Benzol	1.5	41	59
99.0	Pyridine	1.0	33	24
99.0	Alcohol	1.0	20	17
98.9	Water	1.1	17	11
99.0	½ Alcohol, ½ Pyridine...	1.0	00	15
Used liquid NH_3 leaving upon evaporation			0.2	0.00

just as well with ammonia as other substances. As a result of their investigation, Lange and Heffter conclude that the results obtained by Urban's method are always too low, while those obtained by the method of Lange-Hertz are too high, and they suggest to make both tests and take the average. This would seem quite arbitrary, but Lange-Heffter do not consider it worth while to look for a better method as long as no purer ammonia is offered in the market than an article leaving upon evaporation 0.2 per cent. residue.

This was the aspect of the situation in Europe in 1898, and it would seem that the conditions are the same at the present day. (See H. Teichman's book on compressed gases, p. 101. Published 1908.)

In the United States the refrigerating industry has made much quicker progress than abroad. In the same measure as the ice plants multiplied and ice-making machinery became more perfect, the importance of the purity of the ammonia used in the plants became more evident, because impure ammonia produced permanent gases in ice machines, and thereby decreased the efficiency of the plants.

As early as 1892, Hans von Strombeck, then in the employ of the De la Vergne Machine Company, published* the analysis of six samples of so-called "Anhydrous liquid ammonia 100 per cent.," manufactured from different materials by different processes. He evaporated the samples in a flask connected with a long upright spiral condenser cooled with a refrigerating mixture and obtained residues corresponding to the figures given in Table 4. The colorless fluid he obtained

* Proc. Franklin Inst. 6, 21, VI. 92.

TABLE NO. 4.

	A	B	C	D	E	F
	%	%	%	%	%	%
Ammonia (by difference)	98.976	96.984	98.220	99.792	99.321	99.180
Moisture	0.040	0.024	0.079	0.078	0.010	0.032
Colorless fluid	0.950	2.880	1.644	0.117	0.622	0.666
Hartshorn salt	0.030	0.099	0.049	0.004	0.043	0.087
Lubricant oil	0.004	0.006	0.005	0.009	0.004	0.035
Mineral matter	traces	0.007	0.003	traces	traces	traces
	100.000	100.000	100.000	100.000	100.000	100.000

by distillation of the crude residue under the reduced pressure of 200 mm. mercury when it distilled at 106-122° F. By repeated fractional distillation he could separate it into fractions, the boiling points of which corresponded with methylic alcohol, acetone, ethylic alcohol and isopropyl alcohol. Believing only alcohol and acetones present as contaminations of commercial liquid ammonia, von Strombeck proposed to purify it by distilling over metallic sodium. This process has been patented, and it was claimed that liquid ammonia of 99.995 per cent. purity could be obtained by it.

Von Strombeck evidently overlooked benzol and pyridine among the impurities, and for that reason could not have obtained as pure an ammonia as he thought. I have not been able to find that this process has been carried out on a large scale. But his investigation served as an incentive for other manufacturers to improve their product and to furnish to the ice trade an article of such purity as they do now.

In the winter of 1897-98 the writer of this had to rebuild the ammonia works of the Herf & Frerichs Chemical Company, and in order to control the working of the plant the larger of these two test apparati was constructed. It aims to test the ammonia under such conditions as prevail in ice machines, inasmuch as the evaporation takes place under pressure, while the sample is kept at a low temperature by means of a freezing mixture. The test apparatus was permanently connected with the plant and a sample was taken from every 212 pounds of ammonia manufactured. Apparati were changed and purifiers were added to the plant until the resulting ammonia upon evaporation in this apparatus did not leave any visible residue. In order to be surer yet that the ammonia was pure, an upright Liebig condenser, cooled first by liquid ammonia and subse-

quently by liquid carbonic acid, was connected with the flask containing the samples, and even in this case the evaporating ammonia did not leave any visible residue.

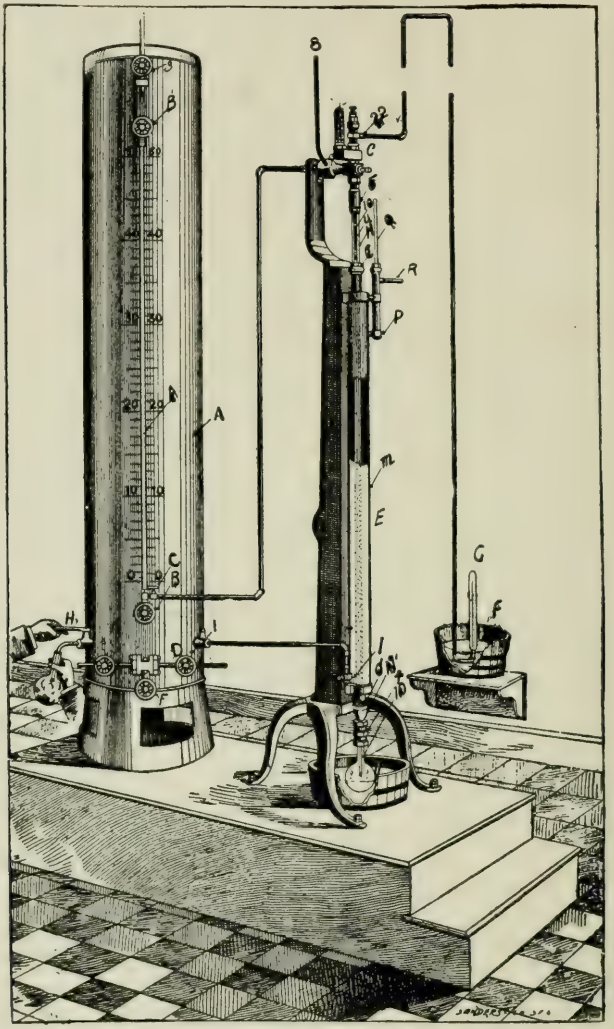


Fig. 11

In one instance 235 consecutive samples, one from every 212 pounds of ammonia manufactured, representing altogether 49,820 pounds of ammonia, were evaporated in the same flask, leaving, upon

evaporation, only 0.0187 grams of a residue containing moisture, iron rust, traces of ammonium carbonate and a little lubricating oil.

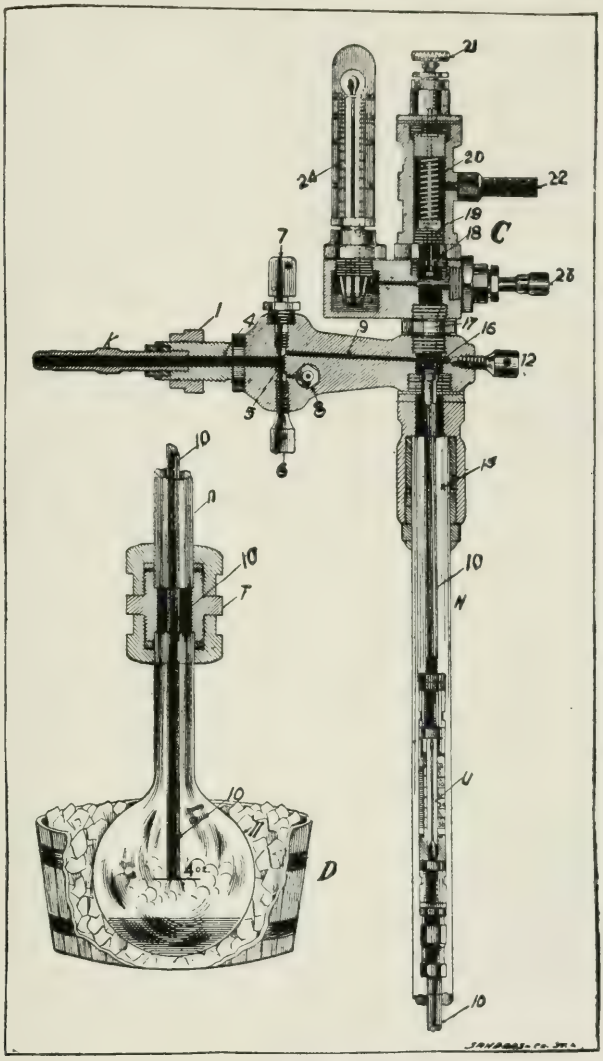


Fig. 12

The apparatus is illustrated by Figures 11 and 12. Figure 13 shows the same apparatus, without the Liebig condenser, attached to a shipping cylinder containing liquefied ammonia gas.

"A" represents a cylinder containing liquid anhydrous ammonia. The test apparatus is attached to the valve "B," as indicated in the cut. Channel 4 terminates in the cross-channel 5, in the ends of which the valves 6 and 7 are located. By opening valves "B" and 6, connection with the outer air can be made through the opening 8, whereby any rust, etc., from the valve can be blown off. By valve 7, connection can be established between channels 4 and 9, the latter extending by means of the tube 10 to the center of the flask 11, which is strong enough to withstand a pressure of 30 pounds to the square inch.

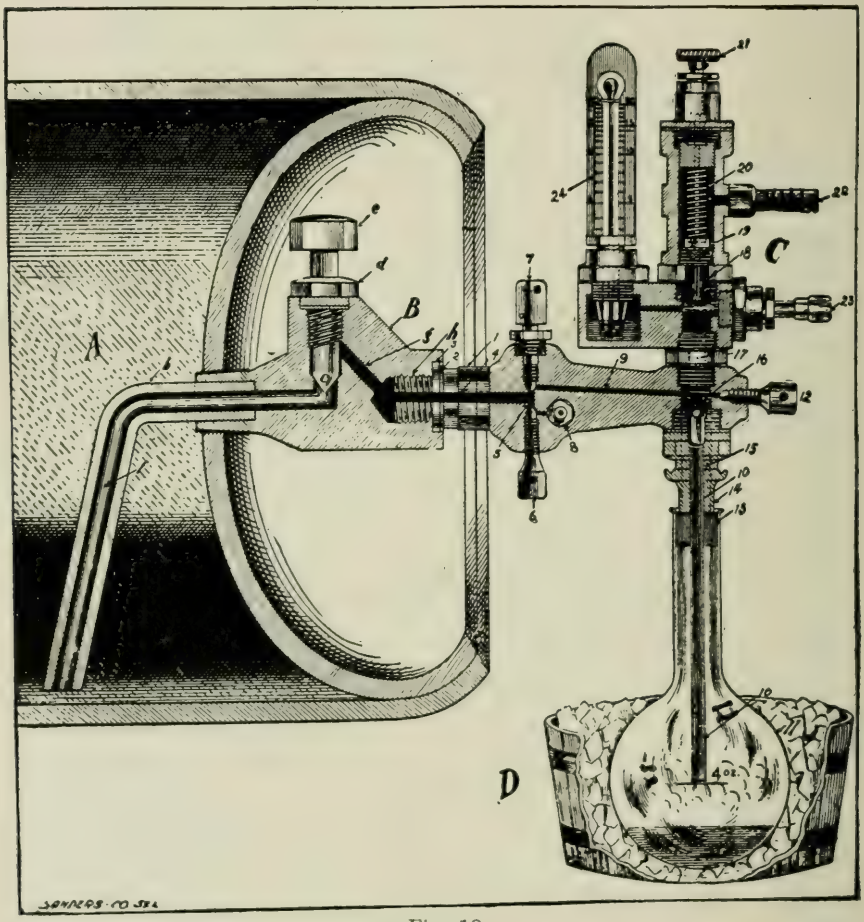


Fig. 13

The interior of the flask connects by way of channels 15, 16, 17, 18 with the automatic valve 19, and the spring 20 (the pressure of which can be regulated by the screw 21) holds the valve 19 in its seat, allowing only gases to escape through channel 22 if their tension is great enough to overcome the pressure of the spring. Valve 23 controls connection with the mercury gauge 24, which indicates the pressure under which evaporation takes place.

In operating the apparatus, it is attached to the cylinder of ammonia to be tested, as indicated by the cut, and valve "B" is opened, all valves of the apparatus being closed. By opening valve 6, some ammonia may be blown off in order to remove the rust or other foreign matter which may have gathered in valve "B." If this has been accomplished, valve 6 is closed, while valve 23 is opened, and by operating valve 7, such quantities of ammonia may be admitted into flask 11 as may be found convenient for the test.

The evaporation of the ammonia in flask 11 begins at once, and by means of the screw 21 the pressure under which the evaporation is to take place may be regulated to the desired degree, which is indicated by the mercury gauge 24. The evaporated ammonia escapes at 22.

If all the ammonia which has been admitted for a sample into flask 11 has been evaporated, a new sample may be filled into the same flask by operating valve 7, the apparatus being in the same condition in which it was at the beginning of the test, except that the flask 11 now contains whatever impurities may have been left from the evaporation of the first sample. In this way a great many tests may be made in succession and the entire contents of the cylinder may be evaporated in the small flask 11, in which remain, at the end of these tests, all the non-volatile impurities which have been contained in a very large amount of ammonia.

The smaller of these apparati has been constructed later, its particular object being to make the test independent from the moisture of the atmosphere. The apparatus is illustrated by Figures 14 and 15, which explain themselves.

The apparatus is attached to the vessel containing the ammonia, as shown in Figure 14, and all rubber tubing is securely fastened with copper wire wherever such joints occur. When ready for use the main valve on the ammonia cylinder is opened, and by opening the thumbscrew 1 some ammonia is blown off in order to remove rust and dirt which may have accumulated in the valve, this also will remove the

small quantities of oil which may have been used for lubricating the screw on the valve stem, and which are always liable to be present in the interior of the valve.

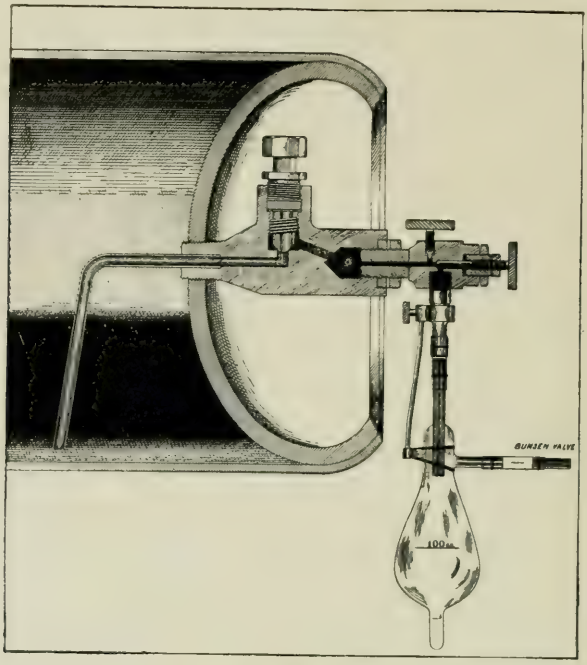


Fig. 14

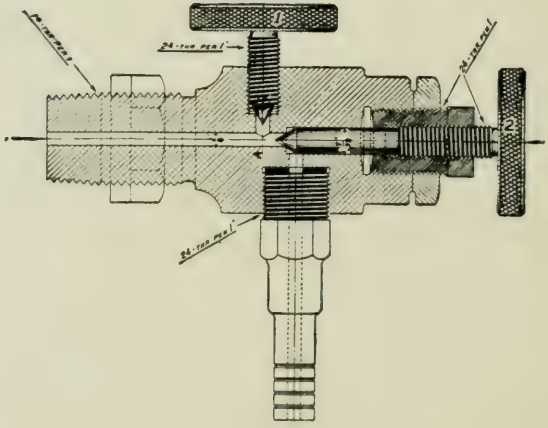


Fig. 15

If sufficient ammonia has been blown off to clear the valve, thumbscrew 1 is shut, and by opening thumbscrew 2 a sample of ammonia is admitted to the test bottle. Care must be taken that ammonia is not admitted too quickly, otherwise the pressure in the bottle will become too great and either the bottle or the rubber connections are liable to burst. A Bunsen valve permits the ammonia vapor to escape, but prevents the moisture of the air from entering the bottle.

The sample is permitted to evaporate while the apparatus remains attached to the cylinder. Evaporation may be hastened by dipping the graduated tail of the test bottle in cold water, whereby a gentle and steady boiling of the ammonia is kept up. Care should be taken not to dip the test bottle too deep into water, otherwise the ammonia may boil too rapidly and the bottle may explode by excessive pressure. The slower the sample is evaporated the more reliable is the test. One hour and a half is a good time for evaporating 100 c.c. of ammonia in this apparatus. If evaporation is effected in much less time, the rapidly boiling ammonia will take with it some of the impurities, particularly hydrocarbons, if such are present, and an inferior ammonia may show a good test.

During the evaporation the tail of the test bottle will be heavily coated with ice, which will readily melt off after the sample of ammonia has evaporated by gently agitating water in the surrounding vessel.

If 100 c.c. are taken for the test, and if there remains some liquid in the tail of the test bottle, each subdivision in the scale indicates 1/10 of 1 per cent. by volume in the ammonia.

A second and third sample may be evaporated in the same bottle without removing the apparatus from the cylinder, and this may be continued until the entire contents of a cylinder has been evaporated, in which case the test bottle will contain all of the impurities which have been contained in the entire cylinder. Before taking a new test some ammonia is blown off by opening thumbscrew 1, in order to remove as much as possible the traces of oil which may have escaped into the valve from the lubricant used for the valve stem.

If more accurate results are desired, the Bunsen valve on the side outlet of the flask is replaced by a bent glass tube leading the ammonia gas into water, where it is absorbed. A Bunsen valve attached to the end of the glass tube which dips into the water prevents the water from backing up into the test flask. The amount of the ammonia used for the test is then ascertained by titrating the solu-

tion of ammonia in water, and the amount of residue left upon evaporation is determined by weighing the test flask before and after the test on a chemical balance. Care must be taken to close the outlets of the flask and to have constant temperatures while weighing, also to have the flask entirely filled with ammonia gas, in order to exclude errors resulting from the difference in the specific gravities of air and ammonia gas.

Liquefied ammonia gas seems to be an absorbent for permanent gases. They may be determined with the aid of this apparatus by collecting them in a eudiometer filled with water after the ammonia gas has been absorbed in the water of a pneumatic trough. If this be done, care should be taken to use water which has been freed from air by protracted boiling, since ammonia gas disengages air from water which is saturated with it.

Small quantities of alcohol and water can be determined in liquid ammonia by treating it with metallic sodium and measuring the quantity of hydrogen evolved. The mode of operation is as follows:

Sufficient sodium is inserted into the test flask which is then connected with the test valve and provided with an extension tube and eudiometer filled with water and standing in a pneumatic trough. Some liquid ammonia is admitted, which dissolves the sodium to a dark blue liquid, the evaporating ammonia expelling the air from the flask. If the ammonia has evaporated to 1 c.c., and if the air has been expelled, the glass tube is inserted into the pneumatic trough and under the opening of the eudiometer, and ammonia for the sample is admitted. Hydrogen is evolved at once as a result of the decomposition of water and alcohol contained in the ammonia. When the sample has evaporated to 1 c.c., the volume of hydrogen is measured and the amount of ammonia absorbed in the water of the pneumatic trough is determined by titrating, giving the data for the calculation. The results obtained by this method are a little too high, because ammonia is decomposed slowly by sodium to sodium amide and hydrogen. But it would seem that this secondary reaction is so slow that the result is only slightly affected.

With this apparatus a series of tests have been made with a view of ascertaining its accuracy in determining the various impurities which are most frequently contained in commercial liquefied ammonia gas.

As a basis, liquid ammonia was used which had been manufactured in the regular run of the works from sulphate of ammonia

previously purified from all volatile carbon compounds, and in the manufacture of the product great care was taken that all the moisture was eliminated. For this reason it was certain that bodies like benzol, pyridine, alcohols and other carbon compounds could not be present, and the limit of water was ascertained by analysis to be less than 2 milligrams in 100 grams of liquid ammonia. The determination of water was made by adding an ammoniacal solution of metallic sodium to the liquid ammonia to be analyzed and collecting the hydrogen, which was evolved by the reaction of the sodium upon the water in the sample; 100 grams of the liquid ammonia treated in this way produced 2.4 c.c. hydrogen. If all the hydrogen had been produced from water, 2 milligrams of water must have been present, but it is well known that ammonia itself decomposes slowly with sodium into sodium amide and hydrogen, and for this reason part of the hydrogen may have come from the ammonia, in which case the water present would be less than 0.002 per cent. As a fact, I will state that about one-half of the hydrogen was developed rapidly right after the sodium solution had been added, while the balance accumulated from minute bubbles during the time of evaporation of the entire hundred grams of the liquid ammonia, and for this reason it is quite possible that the second half comes from the decomposition of ammonia. Therefore, under no circumstances could more than 0.002 per cent. water be present, and it is possible that the quantity of water in the sample was not more than half of that amount. Table 5 gives the result of five tests made with this ammonia in the smaller of the two tests apparati, and from the uniformity of the results and the insignificance of the residues, the purity of the liquid ammonia is evident.

TABLE No. 5.

80 gr. liquid NH_3 left after evaporation 0.003 gr.
160 gr. liquid NH_3 left after evaporation 0.003 gr.
240 gr. liquid NH_3 left after evaporation 0.003 gr.
320 gr. liquid NH_3 left after evaporation 0.005 gr.
400 gr. liquid NH_3 left after evaporation 0.007 gr.
Residue from evaporation, 0.00175%.
Ammonia by difference, 99.99825%.

The residue consisted or iron oxide shown by potassium ferrocyanide and little lubricating oil.

With ammonia of this purity the experiments of Lange and Heffter have been repeated. The results I have given before. In addition a series of samples containing variable, but known quantities

of benzol, pyridine, alcohol and water, have been evaporated in the new apparatus, and the residues left after evaporation have been ascertained as given in Table 6. From this table it is evident that the quantities of the additions which evaporate with the ammonia decrease if less of the addition is present.

TABLE No. 6

Evaporated with Liquid NH_3.	Benzol, 0.527 gr.	Pyridine, 0.652 gr.	½ Alcohol, ½ Pyridine, 0.966 gr.	Acohol, 0.676 gr.	Water, 0.673 gr.
First 100 c.c.....	0.258	0.142	0.142	0.099	0.077
Second 100 c.c.....	0.178	0.135	0.131	0.089	0.066
Third 100 c.c.....	0.077	0.084	0.117	0.077	0.061
With 300 cc. evaporated gr.....	0.513	0.361	0.390	0.265	0.204
With 300 cc. evaporated %.....	97	55	40	39	30

Table 7 shows the same results differently arranged. It gives the proportion of the addition evaporated with the ammonia to the total amount of the addition present before the evaporation, and a marked difference is observed between benzol on the one side and pyridine, alcohol and water on the other side. While the percentage evaporated seems to be the same for varying quantities of the addition present in the case of pyridine, alcohol and water, it increases rapidly with a decreasing addition of benzol.

TABLE No. 7.

Benzol,		Pyridine.		Alcohol		Water.	
Present % of Ammonia	Evap. % of Benzol	Present % of Ammonia	Evap. % of Pyridine	Present % of Ammonia	Evap. % of Alcohol	Present % of Ammonia	Evap. % of Water
1.50	59	1.00	24	1.00	17	1.10	11
0.65	49	0.81	22	0.84	14	0.84	11
0.34	66	0.64	26	0.72	15	0.75	11
0.11	84	0.47	22	0.61	16	0.66	11

The limit of accuracy of this mode of testing has been ascertained in a special series of experiments as follows:

For Water to 0.002 gr. in 100 gr. Ammonia
For Alcohol to 0.006 gr. in 100 gr. Ammonia
For Pyridine to 0.009 gr. in 100 gr. Ammonia
For Benzol to 0.110 gr. in 100 gr. Ammonia

In other words, 100 c.c. samples of liquid ammonia containing these additions leave, upon evaporation, a visible residue of at least 1 milligram.

The constant desire to make the elimination of volatile carbon compounds as certain as possible has led to an improved process for the purification of ammonia. The process is carried out in three steps:

First—Crude sulphate of ammonium is heated to 200° C. to volatilize carbon compounds and to destroy nitrogenous organic compounds by the Kjeldal reaction.

Second—Sulphate of ammonium thus purified is heated to 400° C. to decompose it into pyro-sulphate of ammonium and pure ammonia gas.

Third—Pyro-sulphate of ammonium is treated with water and volatile ammonium compounds coming from the distillation of crude ammoniacal liquors to make crude sulphate of ammonium, which is introduced into the first step, thus closing the circle of operations.

This process has considerable economy over the present process of manufacturing ammonia from sulphate of ammonium, inasmuch as it does not consume theoretically any sulphuric acid and only 95 per cent. of the lime which is used at the present time. For this reason it has been patented in the United States,* and will be tried on a large scale in the near future. It is too early to say anything more definite than what the patent specification gives, but I hope that I may report more fully about the working of the process at some later meeting.

Discussion.

Question: I would like to know at just what temperature the decomposition of ammonium sulphate begins?

Answer: Decomposition of ammonium sulphate begins at 290° C. and becomes rapid at 330° to 350° C. The reaction may be hastened by heating to 400° C., but if this be done much pyro-sulphate of ammonium is formed from the acid sulphate of ammonium. At a higher temperature considerable quantities of ammonia are decomposed and free nitrogen is evolved. On this occasion I would like to call attention to an error which has gone through the chemical handbooks for more than half a century. It is generally stated that sulphate of ammonium melts at 140° C. This is not true. Neutral sulphate of ammonium does not melt at all, but upon heating it decomposes into acid sulphate of ammonium and free ammonia gas, and it is the acid sulphate of ammonium which melts at about 140° C.

*U. S. Patent 905,415. December 1st, 1908.

Mention of this fact has been made by Watson Smith in the journal of the Society of Chemical Industry, Vol. 14 (1895), page 629, but the error has not been corrected in larger hand-books, except in the newest editions of Gmelin-Kraut-Friedheim, where both statements are given, leaving it to the reader to decide which observation is correct.

QUESTION: In carrying out your new process it would seem necessary in the circle of operations to dissolve the acid salt in water, saturate with ammonia and evaporate the solution to dryness, thus causing considerable expense.

ANSWER: This is not absolutely necessary. Acid sulphates which have been deprived of part of their ammonia at temperature of 300° C. or over are capable of reabsorbing ammonia gas rapidly at a lower temperature. Pyro-sulphates seem to do the same in presence of steam. Therefore it is possible to produce pure ammonia by alternately saturating acid sulphates and pyrosulphates with impure ammonia gas and steam at lower temperatures and recovering pure ammonia gas from same by advancing its temperature to the point of decomposition.

QUESTION: At which temperature will absorption of ammonia gas take place?

ANSWER: It has been observed that sulphate of ammonium deprived of part of its ammonia at 300-400° C. will reabsorb ammonia gas rapidly at temperatures which are less than 300° C.

THE SANITARY CONDITION OF THE SOUTHERN END OF LAKE MICHIGAN

By

J. H. BREWSTER

Hardly more than fifty years ago the sanitary condition of the southern end of Lake Michigan offered no problems. The lake was a body of pure water and, save at a few widely separated points where cities were springing into existence and commercial life was developing, its shores were uninhabited and its waters undisturbed by shipping, while even at those places household sewage and industrial waste had not become a sufficient nuisance to demand its destruction. The time came however, when these wastes had to be gotten out of the way and naturally enough the great body of water lying just at hand, seemingly capable of receiving and destroying any amount of sewage at no expense whatever, became the dumping ground.

When the growing cities could no longer depend upon ground and surface waters for a supply, just as naturally they turned also to the great lake for water, and now for many years they have been pouring sewage into Lake Michigan through one pipe and pumping out a water supply through another.

Is it not strange that, in this country at least, the development of our national resources, the building of cities, the creation of great industries, has always meant destruction of the natural purity of lakes, stream and underground water? But such has been the case and to-day the cities along Lake Michigan are awakening to the fact that their most valuable civic asset, a pure water supply, is in great danger of being destroyed, and that already they have sacrificed hundreds of lives on the altar of ignorance and carelessness and wasted at the sick bed and cemetery far greater resources than would have preserved their water supply in its pristine purity.

The shore line of Indiana along Lake Michigan is very short compared with that of other states, but what Indiana loses in miles of coast is made up in other ways. Nearly all of the extreme southern end of the lake with its burden of sewage and shipping adjoins Indiana. And as the industrial march of Chicago progresses to the

south and eastward, mile after mile of shore is losing its sandy beach and taking on the aspects of commercialism. Already Indiana's cities extend from Michigan City to Chicago and within fifteen years will have a greater population than is gathered at any other point on the lake save at Chicago herself.

The questions of pure water supplies and sewage disposal are more closely interdependent here than is the case with river cities which may suffer from the sewage discharged by up stream cities but whose water is not usually affected to any great extent by its own wastes. And the problem is not to be solved for the benefit of the lake cities alone. The conservation of the purity of the southern end of Lake Michigan is in the near future to be a factor in the development of all northern Indiana cities. These cities are now depending upon deep well supplies but it is only a question of time when because of the failure of the underground water to meet the demands of an increased population they too will be obliged to go to the lake.

It has been known for many years that the quality of the water of Lake Michigan was constantly being injured by the continued addition of domestic sewage and trade waste from every city and industry on her shores. The concentration of this dejecta of civilization at the larger cities has compelled the continued extension of water intakes further and further into the lake in an effort to reach pure water outside the zone of pollution.

Some years ago the city of Chicago found it was not longer possible to sewer into the lake and depend upon it at the same for a water supply. The death rate from intestinal diseases due to polluted water was even then far above normal and a change of either the water supply or sewage disposal became imperative. The problem was in part solved by the construction of the Chicago drainage canal which diverts the sewage of a large part of the city of Chicago from the lake into the Illinois river through which it flows to the Mississippi and thence to the Gulf of Mexico. After the addition of sewage to the lake was discontinued the polluted area around Chicago began to diminish in size until at the present time the four mile cribs supplying the city are obtaining a good quality of water and the water at the two mile cribs is unwholesome only part of the time.

That the new system of disposing of the sewage has been a benefit to the city is readily shown by the gradual lowering of the typhoid fever death rate, and also by the fact that the prevalence of typhoid fever in Chicago is less than in neighboring cities. For instance, it is

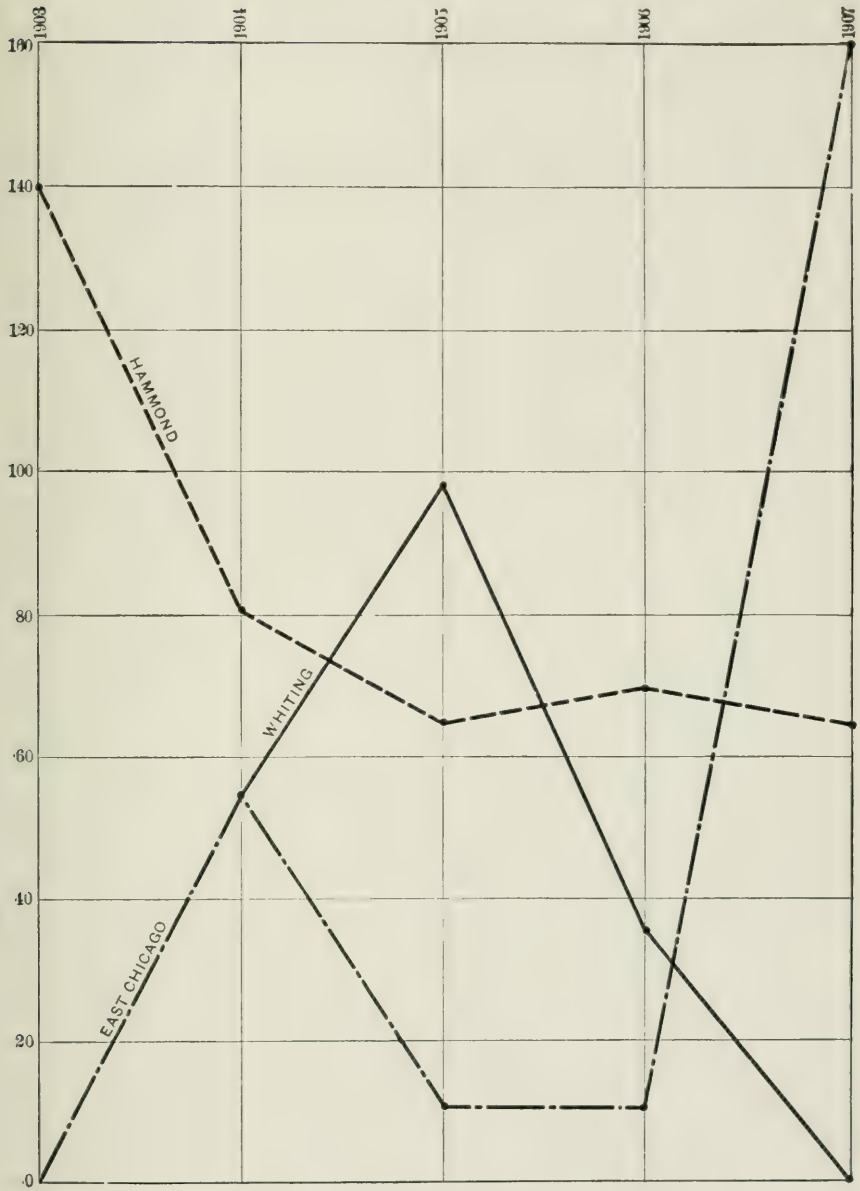
Chart No. 1

LAKE COUNTY IND.

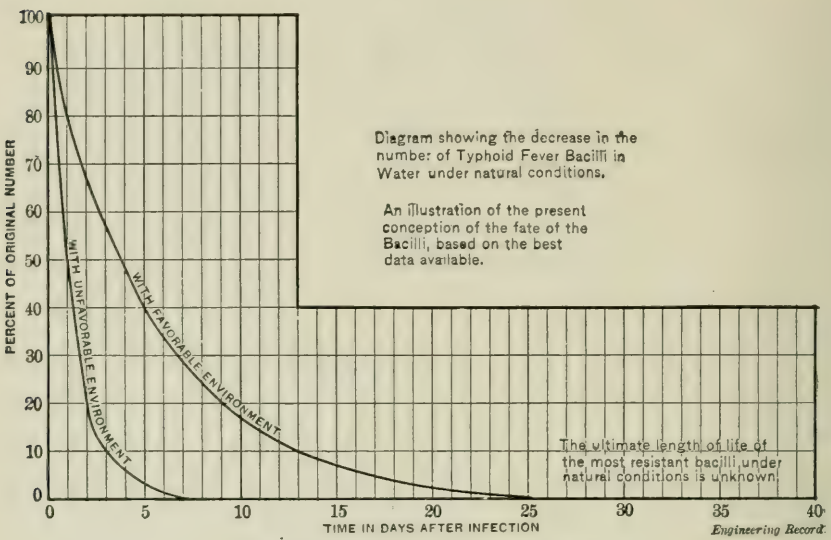
DIAGRAM SHOWING

TYPHOID DEATH RATES PER 100,000

From 1903 to 1908.



claimed by the City Board of Health of Hammond, Indiana, that that city with its 24,000 population had this last year half as many cases of typhoid fever as the whole city of Chicago with a population one hundred times as great.



THE LONGEVITY OF TYPHOID BACILLI

Chart No. 1 was marked out from the statistics furnished by the Board of Health showing the death rate per 100,000 in Hammond, Whiting and East Chicago, from 1903 to 1907 inclusive. While it is of little value owing to the short period that it covers and the failure on the part of the doctors to report the cases, yet as this error lowers the death rates instead of increasing them, the chart is to be considered.

Hammond in 1903 had a death rate of 140, it then drops to 80 and in 1905 reaches 66 per 100,000 which is the lowest point for the last five years.

Whiting does not show any returns until 1904 when the rate was 55 and then drops again until there is none in 1907.

East Chicago had no deaths in 1903. In 1904 it had a rate of 55. Dropping again in 1905 and 1906 but in 1907 reached 160. This is probably due to the records being more completely kept than in the previous years rather than to the great increase in typhoid fever.

It has been accepted as a general rule that a continued typhoid

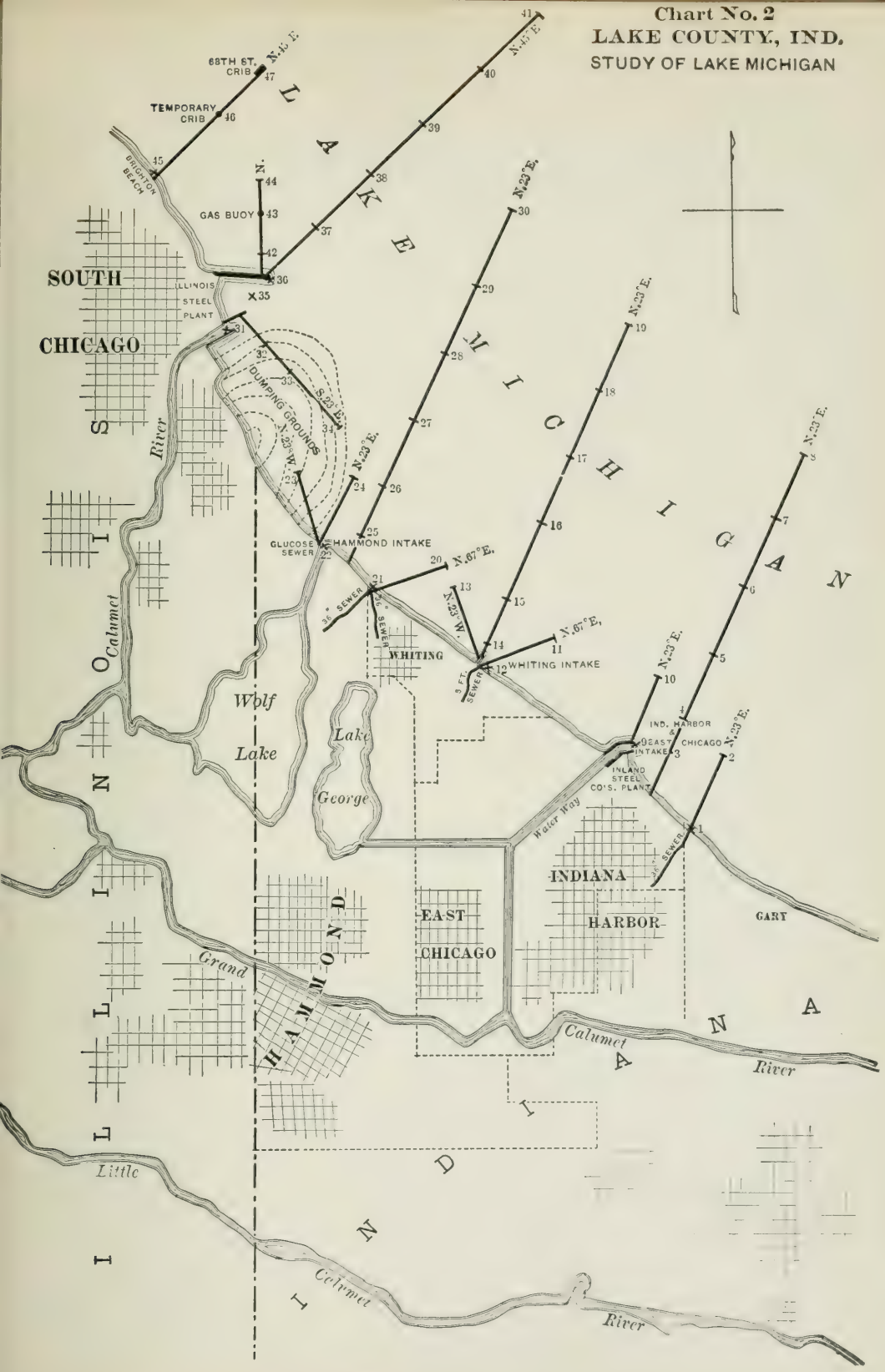


Chart No. 2
LAKE COUNTY, IND.
STUDY OF LAKE MICHIGAN
LAKE MICHIGAN
68TH ST. CRIB
TEMPORARY CRIB
BRIGHTON BEACH
GAS BUOY
SOUTH CHICAGO
ILLINOIS STEEL PLANT
DUMPING GROUNDS
GLUCOSE SEWER
HAMMOND INTAKE
WHITING
WHITING INTAKE
IND. HARBOR EAST CHICAGO INTAKE
INLAND STEEL CO'S. PLANT
Water Way
INDIANA HARBOR
EAST CHICAGO
GARY
HAMMOND
Wolf Lake
Lake George
Grand Calumet River
Little Calumet River
Calumet River
ILLINOIS
INDIANA

death rate above 20 is an indication that something is at fault with the public water supply. As is shown here for the last five years, the death rate of all three of these cities has been more than double this figure and has several times been six and eight times greater than this limit of safety.

Recognizing the fact that these cities, which are rapidly growing into what will undoubtedly be one of the greatest business sections of the world, will suffer serious material injury and eventually be compelled as was Chicago to devise some means of keeping down this typhoid fever loss, the health officers of Hammond, Whiting and East Chicago in the summer of 1908 requested the State Board of Health to make a sanitary survey of the lake near those cities with the following objects in view: (1) to determine the real character of the different water supplies with respect to their present sanitary conditions; (2) to determine the amount and character of the sewage entering the lake; (3) to determine the distribution of this sewage in the lake under the different prevailing winds and lake currents which occur along the lake frontage of these cities; (4) to study the probable future quality of the sewage and suggest suitable means for its disposal.

In accordance with the request of the local health boards, on August 13, 1908, the State Board of Health established a temporary bacteriological laboratory equipped for making colony counts and the presumptive test for B. Coli.

Forty-seven sampling points covering a territory of five miles off shore from Indiana Harbor to the Chicago two mile crib off Brighton Beach were located and marked by buoys. Samples were taken daily at these points from August 19th to and including Sept. 26th.

The sampling points were located so as to establish a line of limitation of sewage distribution straight into the lake from each water intake; at every sewer outlet and on a diagonal in each direction from the mouth of each sewer. From a careful study of the bacterial content of the water at these points on different days with varying winds it was possible to determine the quality of the sewage entering the lake and how far it was carried in any direction, and also to gain a substantial idea of the prevailing currents and counter currents. Chart No. 2 shows each sampling point with the number used to indicate it. Samples were taken from each intake and at each mile point in a line N. 23° E. for five miles into the lake; at the mouth of the Indiana Harbor sewer and one mile from it N. 23° E.; at the mouth of the har-

bor of the Inland Steel Company's plant and one mile from it N. 23° E.; at the Standard Oil Company's sewer, one mile from it N. 67° E. and one mile N. 23° W.; at the mouth of two sewers, one a 36-inch sewer from Whiting and the other a 36-inch sewer from Robertsdale, at a point one mile N. 67° E. from these sewers; at the mouth of the Glucose sewer one mile N. 23° E. and one mile N. 23° W. from the Glucose sewer; at the mouth of the Calumet river and at points one half mile, one mile, and two miles S. 23° E. from the light house; at the government fog horn and every mile for five miles in a line N. 45° E. This point, which is No. 41, is practically seven miles N. 23° E. from the Hammond intake. Points were located at one-half and one and one-half miles north from the fog horn and at the government gas buoy; at Brighton Beach bath house, the temporary crib for the construction of the new water works tunnel and at the 68th street crib.

The direction and velocity of the wind and the direction of lake currents and counter currents were noted daily. The investigation necessitated the collection and bacterial analysis of 606 samples of water, and several chemical analyses of samples taken from different points in the lake and from the city supplies. All lake samples for bacterial analysis were collected from a water level 10 feet below the surface. Since there are practically no wells throughout this section of the state the only source of supply is the lake.

The Drainage of the Calumet Region.

The southerly end of Lake Michigan bordering Lake County is affected by the drainage of the Calumet river and of Wolf Lake which receives the sewage of the Glucose Works and by the sewage from Whiting, East Chicago and Indiana Harbor. The character of the lake water will shortly be influenced to a greater degree than at present by the opening of a canal water way which will connect Lake George and the Calumet river with the lake at Indiana Harbor. The Grand Calumet river is a tortuous channel which has its origin in Lake Michigan and after running through Lake County empties back into the lake. One end is about three miles east of Gary and the other terminates at South Chicago. However, at the present time the mouth east of Gary is closed by a sand dune, thus leaving but one outlet at South Chicago. The Calumet river together with the little Calumet which empties into it near Hegewisch, Illionis, besides receiving the drainage of the Northern Indiana cities and South Chicago, receives the drainage and storm flow of a great many small towns in Lake County and in the Illinois territory lying south of Chicago.

Chart No. 3
LAKE COUNTY, IND.
DIAGRAM SHOWING
MAXIMUM BACTERIAL COUNTS
AT ALL SAMPLING POINTS
Aug. 19, 1908 to Sept. 27, 1908
INLAND STEEL CO'S. PLANT
WHITING
GLUCOSE SEWER
Calumet River

The Lake Currents.

As the outlet of the lake is small in comparison with the quantity of water it contains, there is no direct flow in the lake and the movements of the water are entirely dependent upon local winds which vastly over-balance the general movement of translation and drive the water one way or the other according to their direction, velocity and duration. The atmospheric temperature also influences these movements, and near the mouth of large streams, these too, have their effect.

The friction of the wind blowing over the surface of a large body of water tends to produce a surface current of the water in the same direction, and if the wind continues to blow from one direction a general surface drift of the water in that direction is established. These induced currents may be interrupted at times or even reversed, but as a whole they represent an advance movement in the direction of the prevailing winds. It is the general impression that the prevailing currents are from the west to east along the southern shore of the lake and from east to west along the northern shore or counter clockwise around the entire lake, and water works intakes in some instances have been placed with the idea that these currents would act as a protection to their water supply. This idea is pronounced a fallacy by Major W. V. Judson, Corps of Engineers, of the War Department, who has found no positive currents in Lake Michigan and after a careful study of the Lake Currents concludes that they may run in any direction at any time according to the direct influences of the wind and atmospheric temperature.

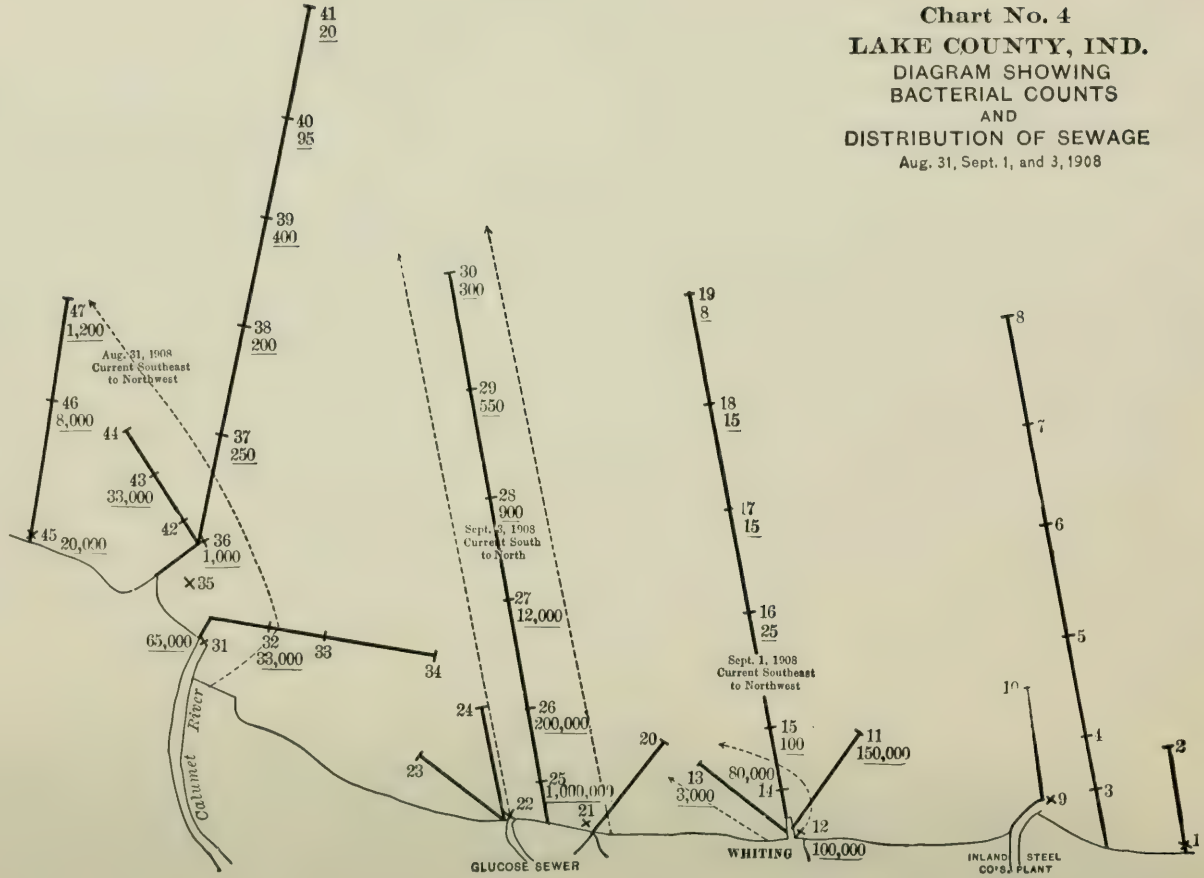
Currents have been noted at the Hammond water works where the sewage from the Glucose works goes into the lake and is carried by a current from west to east. In a short time it turns toward the shore and on reaching the shore is deflected from east to west until it again reaches the flow from the sewer when it is carried over the original course, thus producing a whirlpool effect around the Hammond intake. Within the area covered by this circular current large quantities of the glucose effluent was always found. These counter currents have been noticed not only near the shore but have been encountered five and six miles out into the lake on perfectly calm days when there was apparently no reason for the change in direction of flow. The government engineering crew on the U. S. S. Search who were making a survey of the bottom of the lake from Gary to South Chicago at the time of this investigation stated that as many as three

Chart No. 4

LAKE COUNTY, IND.

DIAGRAM SHOWING
BACTERIAL COUNTS
AND
DISTRIBUTION OF SEWAGE

Aug. 31, Sept. 1, and 3, 1908



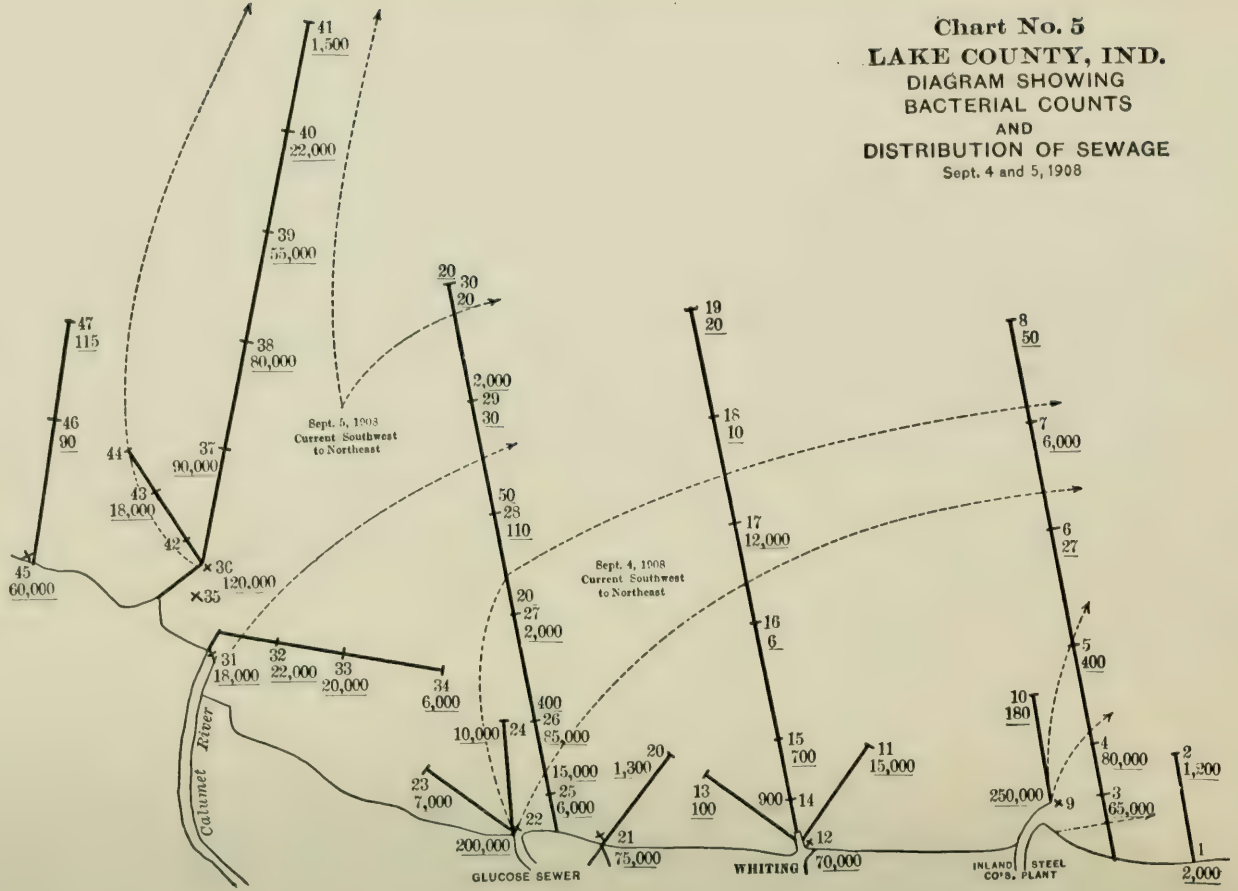
distinct currents going in opposite directions have been found within linear distance of two miles and that these currents were apparently stronger on a calm day than when the lake was rough.

A probable reason for these currents at this point of the lake is that the frontage of Hammond, Whiting and Indiana Harbor is in what might be called a "pocket" lying between the Gary Harbor and South Chicago, and that currents caused by southwesterly winds starting for instance at South Chicago, would strike the projection at Gary and be compelled to return against the direct wind current.

The Grand Calumet river, owing to its large drainage area discharges some water into the lake practically all of the time, but with strong northerly winds a decided current up the harbor has been observed. While the natural appearance of the river water is very turbid at such times, the appearance of the water in the mouth of the harbor is the same as that of the lake water. During flood times and when off shore winds prevail the river water has a high velocity and streams of murky water can be seen in the lake for several miles, reaching to the west as far as the Hyde Park crib of the Chicago water works with the easterly currents, and to the east in front of Hammond with the westerly currents. That the effluent of the Calumet river reaches these points is shown by the bacterial counts of August 31st on Chart No. 4 and September 5th on Chart No. 5.

The current distribution is shown on Chart No. 4 to carry sewage from the Glucose works five miles into the lake where point No. 30 has 300 bacteria per cubic centimeter. On Chart No. 5 when the sewage of September 4 is being carried by westerly currents to point No. 25 off Hammond which has 6,000 bacteria, Point No. 26 or one mile from shore has 85,000 bacteria and point No. 27 or two miles from shore has 2,000 bacteria; point No. 17 or three miles from the Whiting shore has 12,000 bacteria, which is in direct contrast to points No. 16 and 18, which have 6 and 10 bacteria, respectively. Point No. 7, four miles from shore off Indiana Harbor, has 6,000, which is contrasted against point No. 6 with 27 bacteria and point No. 8 with 50 bacteria. This chart shows a distinct current from the Glucose sewer passing over the one-mile point at Hammond, the three-mile point at Whiting and the four-mile point at Indiana Harbor. This shows conclusively that the effluent from the Glucose works is carried by currents for over ten miles into the lake. That the sewage from this plant goes west with easterly currents is difficult to show by bacterial counts, as the differentiation between bacteria from the Glucose works and those

Chart No. 5
LAKE COUNTY, IND.
DIAGRAM SHOWING
BACTERIAL COUNTS
AND
DISTRIBUTION OF SEWAGE
Sept. 4 and 5, 1908



from the dumpings of dredged material in this locality or from those brought in by currents from the Calumet River is impossible, for points between the Hammond intake and South Chicago Harbor always show high counts. That the Glucose sewer does go in this direction is easily determined from direct observation however, as the line of demarcation between the lake water and the stream of sewage is often very distinct.

At Whiting, the Standard Oil Company placed their 5-foot sewer on the east side of the pier as a protection to the city water. That this is no protection is shown on Chart No. 4, when on September 1 there were 100,000 bacteria at the sewer, point No. 12, and 80,000 bacteria at point No. 14, the Whiting intake. On this date four-fifths of the water going to the people of Whiting was the discharge of the Standard Oil Company's sewer. With easterly currents, the effluent from this sewer is thrown against the pier and follows along until it reaches the end, where it is but a few feet from the intake, to which it i carried in a direct compact stream. In this way a more concentrated sewage is pumped to the people than would be the case if there were no pier to direct the flow. Oil is seen on the water at times as far west as the Hammond intake. This was especially noticeable on September 24th. At other times the oil reaches to the east as far as the intake at Indiana Harbor. The water of East Chicago is affected by currents carrying the effluent from the Inland Steel Co.'s Harbor, as is shown on Chart No. 5, in which point No. 9, the mouth of the harbor, has 250,000 bacteria, while 65,000 bacteria are carried by westerly currents to the intake at point No. 3. Observations made by following streams of sewage with a boat from the different places of entrance shows the currents to go in the directions indicated on Charts Nos. 7, 8 and 9, according to the varying winds. These bacterial counts and observations are a positive corroboration of Major Judson's investigations, in which he found that currents may flow in any direction according to the prevailing winds.

Lake Michigan is very shallow along the shore bordering Indiana, and is at certain times rendered more or less turbid by reason of the deposits of clay being stirred up by the wind and currents.

The character of the water for drinking and domestic purposes depends very largely upon its freedom from organic pollution, especially in the form of household sewage. As to this point, the water of Lake Michigan in its normal state approaches absolute purity, and where supplied in this condition its quality is unquestionable. It was

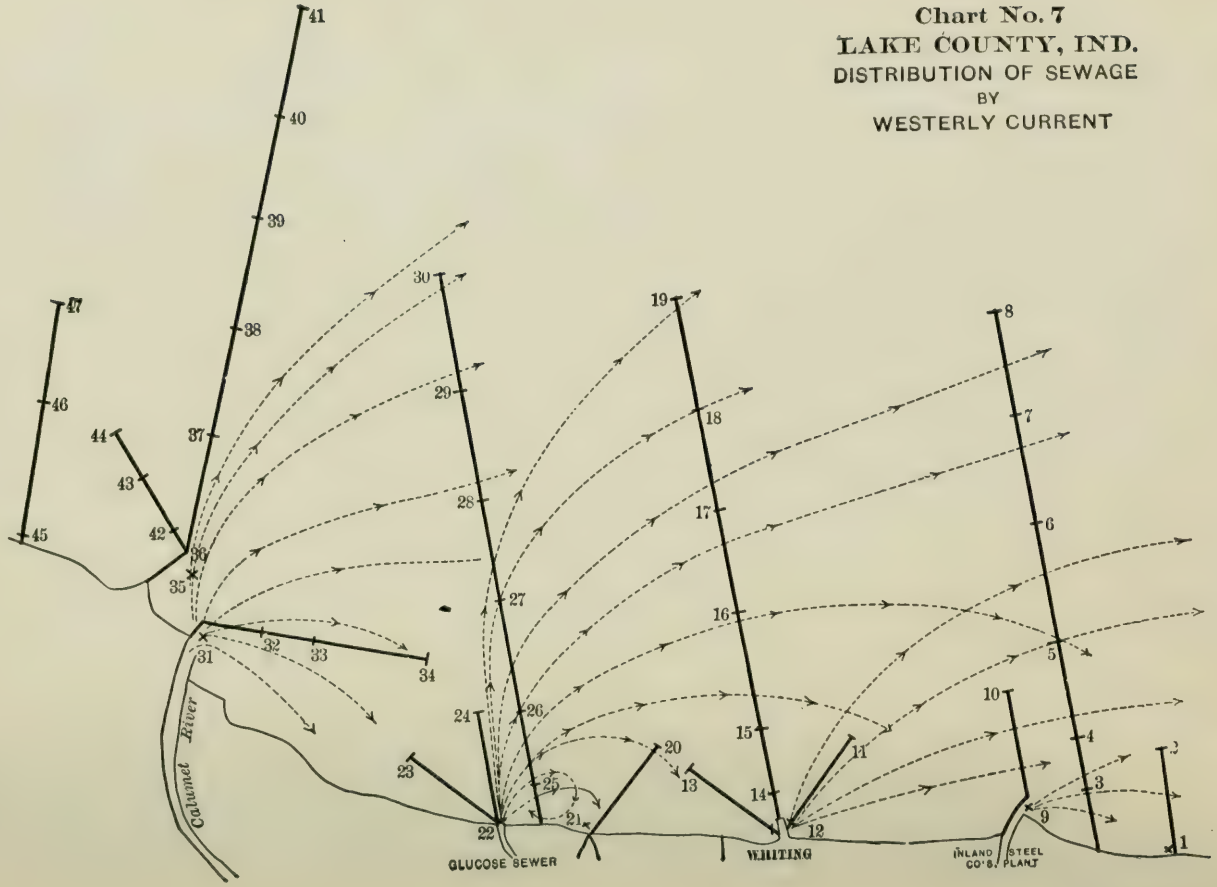


Chart No. 7
LAKE COUNTY, IND.
DISTRIBUTION OF SEWAGE
BY
WESTERLY CURRENT
Calumet River
GLUCOSE SEWER
WHITING
INLAND STEEL CO'S. PLANT

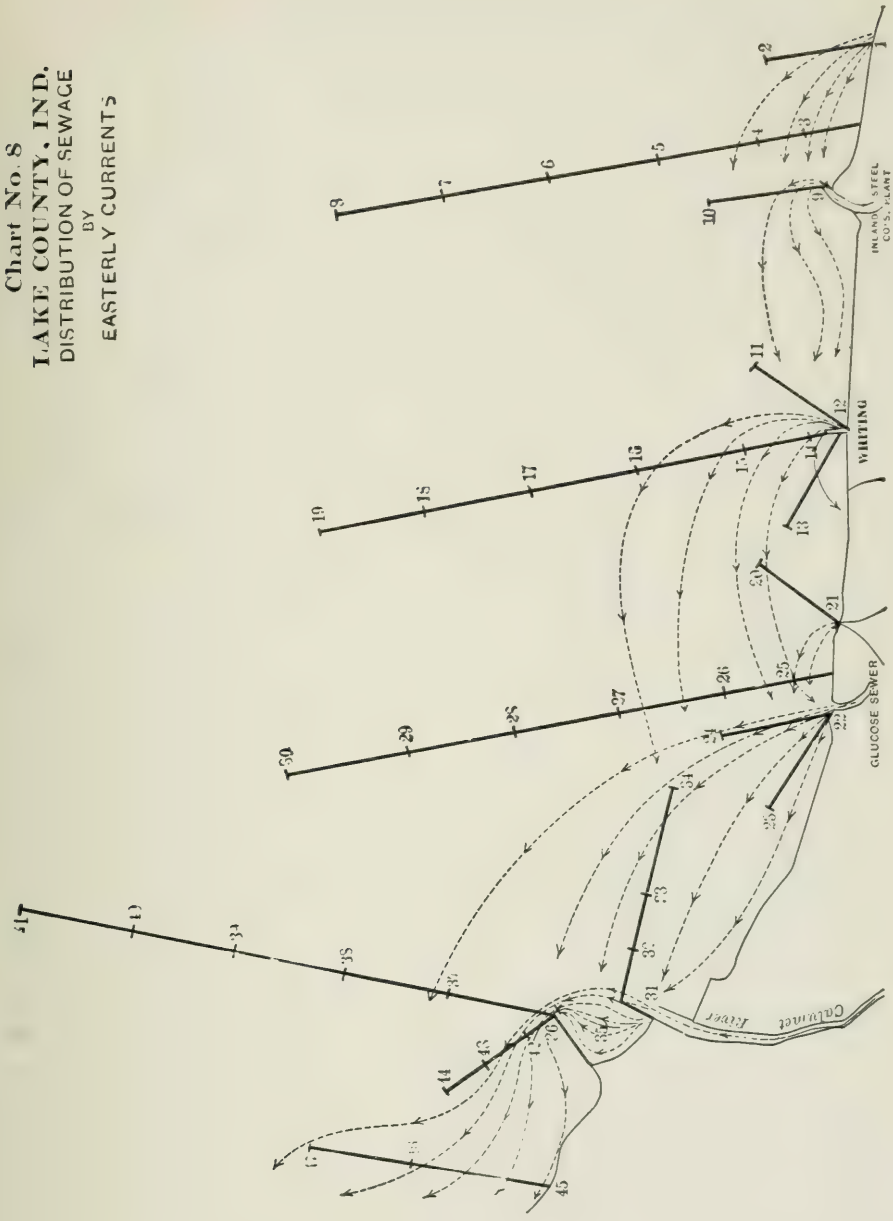


Chart No. 8
LAKE COUNTY, IND.
DISTRICT OF SEWAGE
BY
EASTERLY CURRENTS
WHITING
INLAND STEEL CO'S. PLANT
GLUCOSE SEWER
Calumet River

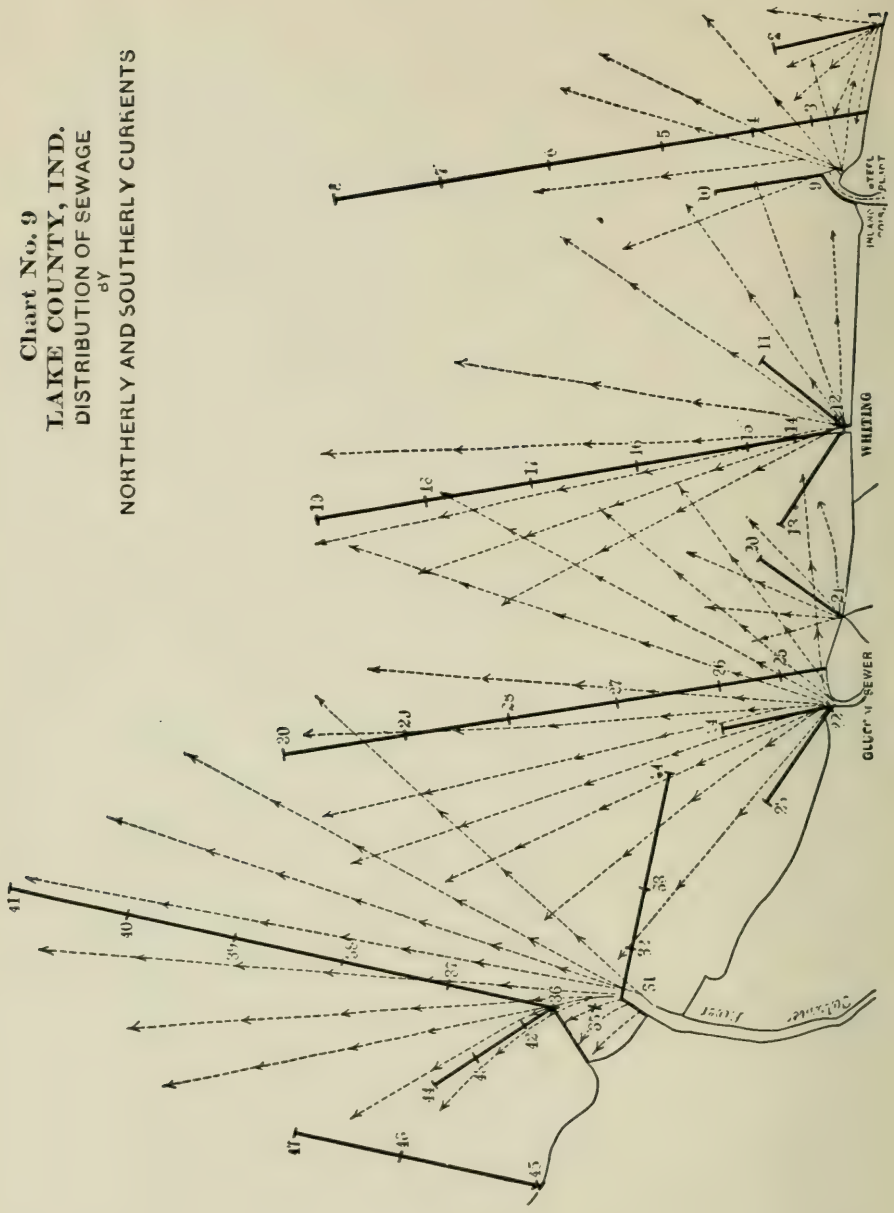


Chart No. 9
LAKE COUNTY, IND.
DISTRIBUTION OF SEWAGE
BY
NORTHERLY AND SOUTHERLY CURRENTS
WHITING
GLOBE SEWER

found at Michigan City during July and August of 1908 that the water one mile in any direction from the mouth of the harbor was practically sterile. Unfortunately, the water intakes are close to shore, and in many instances also near the outlet of public sewers, as at Hammond, where the intake is only 2,000 feet from shore, with two small sewers, one from Whiting and one from Robertsdale to the east, and the Glucose sewer to the west, all of which are within a radius of 3,000 feet from the intake. At Whiting the intake is but 2,000 feet from the shore and the same distance from the Standard Oil sewer. And at Indiana Harbor the intake is 3,000 feet from shore and about 3,500 feet from the mouth of the Inland Steel Company's Harbor and the Indiana Harbor sewer. It therefore becomes necessary to determine whether or not the sewage that enters the lake is carried to the intake of the water supply in order to know the true character of the city water.

Disposition of the Sewage.

Indiana Harbor empties its sewage directly into the lake. This is principally domestic sewage, and as there was no rain during or for some time previous to this investigation, there was no surface wash entering the lake at any time. The sewage of the city runs by gravity into a well, from which it is pumped into the lake by an electrically driven pump through a 36-inch sewer line, which enters the lake about 25 feet from shore at the foot of Lincoln street. This point is about one-half mile east of the water works intake pipe.

At East Chicago both the manufacturing and domestic sewage runs into the Calumet River.

The Whiting sewage flows directly into the lake through three sewer outlets. A 36-inch sewer empties at the same place as a sewer of similar size which takes care of the sewage of Robertsdale. These outlets are close to the boundary line between Hammond and Whiting. There is another 36-inch sewer about one-half mile east of this. The combined drainage of both sewers takes care of the domestic sewage and storm flow of Whiting, with the exception of that portion of the land occupied by the Standard Oil Company's plant. The sewage from this plant enters the lake at the junction of the shore and shipping pier for the oil boats through a 6-foot sewer, which is 2,000 feet from the intake of the water supply of the city.

At Robertsdale the Glucose plant disposes of its sewage through a private sewer to the mouth of Wolf Lake.

The city of Hammond discharges its sewage into the Calumet

River. The system is arranged in districts, with each district having an outlet into the river. The city lies so low that the sewers are below the level of the river, and it is therefore necessary to deliver the sewage to pump wells, from which it is lifted into the river. This system is satisfactory when the pump is in operation, but much inconvenience is caused when the pump is not running, by reason of sewage backing up and overflowing into basements and cellars.

The Calumet River is in reality an open trunk sewer, running through the cities of East Chicago and Hammond. In some places, notably at the distillery at Hammond, the volume of obnoxious decomposing organic matter is very great and becomes a public nuisance. The fact that this stream of sewage flows directly through the city of Hammond renders life along its banks unpleasant and even dangerous, as an excellent opportunity is afforded for flies to carry disease to the tables of private families and restaurants that are near its banks. The river is also a breeding ground for mosquitoes. The amount of sewage that enters the Calumet River is not known at the present time, and can be determined only with great difficulty. For this reason it is impossible to estimate the amount of sewage that is being emptied into the lake by the river. That the quantity is at times very large is plainly shown by the immense streams of turbid water that are carried miles into the lake.

The amount of sewage entering the lake from the harbor at Indiana Harbor is comparatively small, but that it has its effect upon the lake water is shown by the bacterial analyses.

Discharge of Local Sewers Into the Lake.

The most important and most damaging of these sewers is that at the Glucose plant. The average daily discharge is about 2,300,000 gallons. The sewage is in the form of wash and steep waters used in the preparation of the grain and in the processes of manufacture. It contains large quantities of the nitrogenous principles of the corn and other ingredients, which evidently form an excellent culture media upon which bacteria live and multiply. An analysis of the solid matter in the waste water showed a protein content of 36.30 per cent. It is most surprising that this valuable product is allowed to go to waste. At the mouth of the sewer the maximum number of bacteria observed was 3,500,000 per c.c., the minimum 200,000 per c.c., while the average number during the period of investigation was 1,811,000 per c.c., with indications of B. Coli always present. This bacterial content is far in excess of that of the Calumet River, with an average of

86,480. The bacterial content is also much higher than that of the south fork of the Chicago River, commonly known as Bubbly Creek, which receives the waste material of the stock yards, and is considered one of the most vile waters in this section. The average bacterial count shown at the stock yards filter plant was 500,000 per c.c. An instance of the effect of this sewer upon the purity of the lake water is clearly shown on Chart No. 5 by the extreme bacterial count on September 4th at the four-mile point off from Indiana Harbor.

The waste water also deposits large amount of the husk of the corn for some distance around the mouth of the outlet. This organic material in a decomposing and putrefying condition is found in quantities in front of the Hammond pumping station. An analysis of this debris showed a protein content of 12.9 per cent. As 45.4 per cent. of this material was inorganic, the actual protein content of the organic portion was 23.2 per cent.

The anchor line on the buoy marking the Hammond water works intake collected a large quantity of this refuse matter, and was the only anchor line of all the sampling points that was not perfectly clean. The odor of putrefaction emanating from this sewer is noticeable for a considerable distance, and at times, with northerly winds, passengers on trains passing through Robertsdale are made sick.

The streams of sewage from this source have a distinct color, and the line of demarcation between it and the lake water is extremely sharp. A power boat passing through these streams leaves a line of bubbles on the surface marking the exact course traveled. When going in a direct current the sewage does not seem to mix readily with the lake water, and the streams are very distinct until cross currents are encountered.

The effluent from this sewer is the most damaging and the most far-reaching of any source of pollution along the Indiana lake front, and under conditions now obtaining, the citizens of Hammond are being served with a nitrogeneous broth under the guise of drinking water.

The two 36-inch sewers entering the lake at the Whiting and Hammond boundary line discharge an average of 1,500,000 gallons daily into the lake. On account of the extreme dry weather, the amount of sewage entering the lake during the period of investigation was much below the average, and for this reason the bacterial counts were low and the sewage could not be traced for more than a mile into the lake. The 36-inch sewer at Indiana Harbor, which discharges

about 1,000,000 gallons daily, showed exactly the same condition. The effect of these sewers will undoubtedly be much greater under reverse weather conditions, but cannot be compared with the effect of the Glucose sewer. The exact bacterial counts at these sewers could not be ascertained, as the outlets were too far into the lake to be reached from the shore, and it was impossible to reach them from a boat on account of the shallow water. For these reasons the samples were collected about 50 feet in front of the sewer after much dilution had taken place.

The private 6-foot sewer of the Standard Oil Company, which discharges about 18,000,000 gallons daily into the lake, has an especially damaging effect upon the water supply of Whiting. As has already been shown, there are times when four-fifths of the water supply of the city is composed of this sewage. The bacterial content of this sewage is often very low, owing to the antiseptic action of some of the refuse material, especially at times when it contains sulphuric acid. The minimum count showed but ten bacteria per 1 c.c., but at other times the sewage was not benefited by these influences, and the maximum count showed 500,000 per c.c. The average during the period of investigation was 162,821 per c.c.

Shore Wash and Stirring Up of the Bottom.

During storms and windy weather the bottom is stirred up by wave action and suspended matter is carried back and forth between the shore and the water intake. At such times any deposit like the debris from the Glucose plant and the dredgings from the Calumet River along the shore are carried out either by direct currents or by counter currents in reverse winds, and materially increase the turbidity of the water. While such material is usually innocuous, because of its peculiar character and the increased turbidity it gives the lake, it often renders the water unsatisfactory for drinking purposes.

The Dumping of Dredged Material.

On account of the very sluggish motion of the Calumet River, the occasional up-stream currents and the large amount of silt brought into it, the Great Lakes Dredging and Dock Company are almost continually dredging out the bottom of the river in order that the required depth may be maintained for the big freight and ore boats to navigate. The dredged material is carried out in scows and dumped into the lake. This dumping ground covers the territory shown on Chart No. 2, reaching from the mouth of the Calumet River on the

west in a diagonal line nearly to the Hammond intake on the east. The territory allotted for the dumping of this material is understood to be much smaller and much nearer shore. But it is stated by the Superintendent of the Hammond pumping station that there have been times when these scows were dumped within a few hundred feet of the Hammond intake. On September 22 two scows were emptied into the lake at sampling point No. 33, and on September 24th it was observed that two scows were dumped a few feet north of sampling point No. 32.

The effect upon the purity of the lake of the dumping of this material is very damaging, as is shown by the high bacterial counts observed at points Nos. 32, 33 and 34, at all times without relation to the direction of the wind and current. This exceptional condition obtains at no other lake points. The average bacterial count at point No. 32 was 34,322; at point No. 33, 30,385; and at point No. 34 it was 19,228. There were occasionally times during very calm weather when the bacterial count was quite low. The dumping of this material into the lake so close to Hammond intake is very liable to contaminate the city water, since particles held in suspension and water that is mixed with this material is carried near the water intake. This dumping should be carefully regulated, since as this material is principally clay and muck, the smallest particles will be carried great distances.

Chart No. 6 is a diagram showing the per cent. of times that B. Coli was found at each sampling point. At the mouth of the Calumet River it was present 100 per cent.; inside of the harbor, 95 per cent.; at point 36, which is the Government foghorn, was present 92 per cent. There is then a gradual reduction until at point 40 and 41 B. Coli was not found. Point No. 47, the 68th street crib of the Chicago water works, showed B. Coli 40 per cent. of the time. At the Glucose sewer and at the Hammond intake it was always present, and at point No. 30, which is five miles from shore, is present 16 per cent. of the time. The water at the Whiting intake showed Coli 76 per cent. of the time. At the one-mile point we have 22 per cent.; two-mile point, 31 per cent.; the three-mile point, 6 per cent.; while four and five miles from the shore, Coli was not found. The water of Indiana Harbor shows Coli 50 per cent. of the time, and there are Coli found at each point on the line of survey. The five-mile point shows Coli 11 per cent. of the time. The reason for some of these points having a smaller amount of Coli than others is undoubtedly

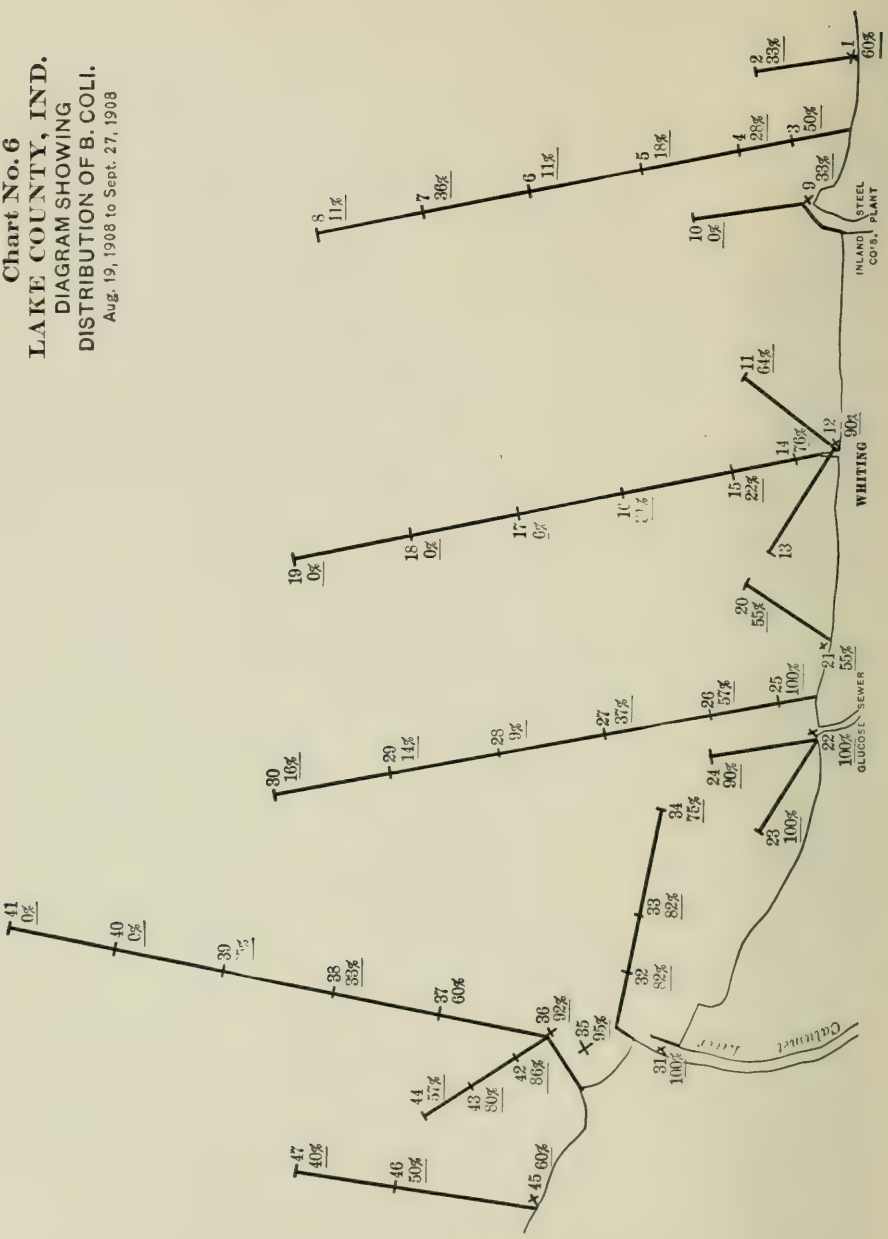


Chart No. 6
LAKE COUNTY, IND.
DIAGRAM SHOWING
DISTRIBUTION OF B. COLI.
Aug. 19, 1908 to Sept. 27, 1908
INLAND STEEL CO'S. PLANT
WHITING
GLUCOSE SEWER
Calumet River

due to elevations in the lake bottom, which has a tendency to convert the currents of sewage away from these points.

On Chart No. 10 there is given the maximum, minimum and average bacterial counts of each sampling point. The interesting feature in this chart is that at point No. 7, which is four miles from the Indiana Harbor shore, the water has a lower bacterial count than at either the three-mile or five-mile point, and that at points Nos. 16 and 17, which are two and three miles, respectively, from the Whiting shore, the bacterial counts are lower than those at points Nos. 15 and 18, which are one and four miles from the shore, and again at point No. 29, which is four miles from the Hammond shore, the bacterial count is lower than either the three or five-mile points. That this is true is evidence that there is more or less of a continuous current of sewage running east and west at about four miles from the shore coming both from the Calumet River and the Glucose sewer.

In summarizing the survey of the southern portion of Lake Michigan adjoining Lake County, the chemical and bacteriological examinations show the water of the lake to be grossly polluted and unfit for use as a source of water supply for drinking or domestic purposes.

This deplorable condition of a once pure and potable body of water is due to the great volume of sewage and manufacturing waste being poured into it by (a) the Calumet River, (b) the Glucose sewer, (c) the Standard Oil Company's sewer, (d) the sanitary sewers of the cities of Indiana Harbor, East Chicago, Whiting and that portion of Hammond known as Robertsdale, (e) the dumping of material dredged from the Calumet River.

There are no uniform currents in this portion of the lake, and sewage once deposited into it may be carried in any direction, depending upon (a) the direction and force of the wind, (b) the lake level, (c) the direction of temporary and induced currents.

The sewage from any one point along the shore may be carried over the intake of any of the water supplies. For this reason the abatement of any one nuisance will not afford a great measure of relief, as the remaining sources of pollution will be amply sufficient to render the water unsafe.

The laying of intakes further into the lake will not provide an adequate protection against impure water, since the zone of pollution extends more than five miles from shore.

The character of the water of Lake Michigan adapts it so well to all domestic and industrial uses that cities along its shore cannot

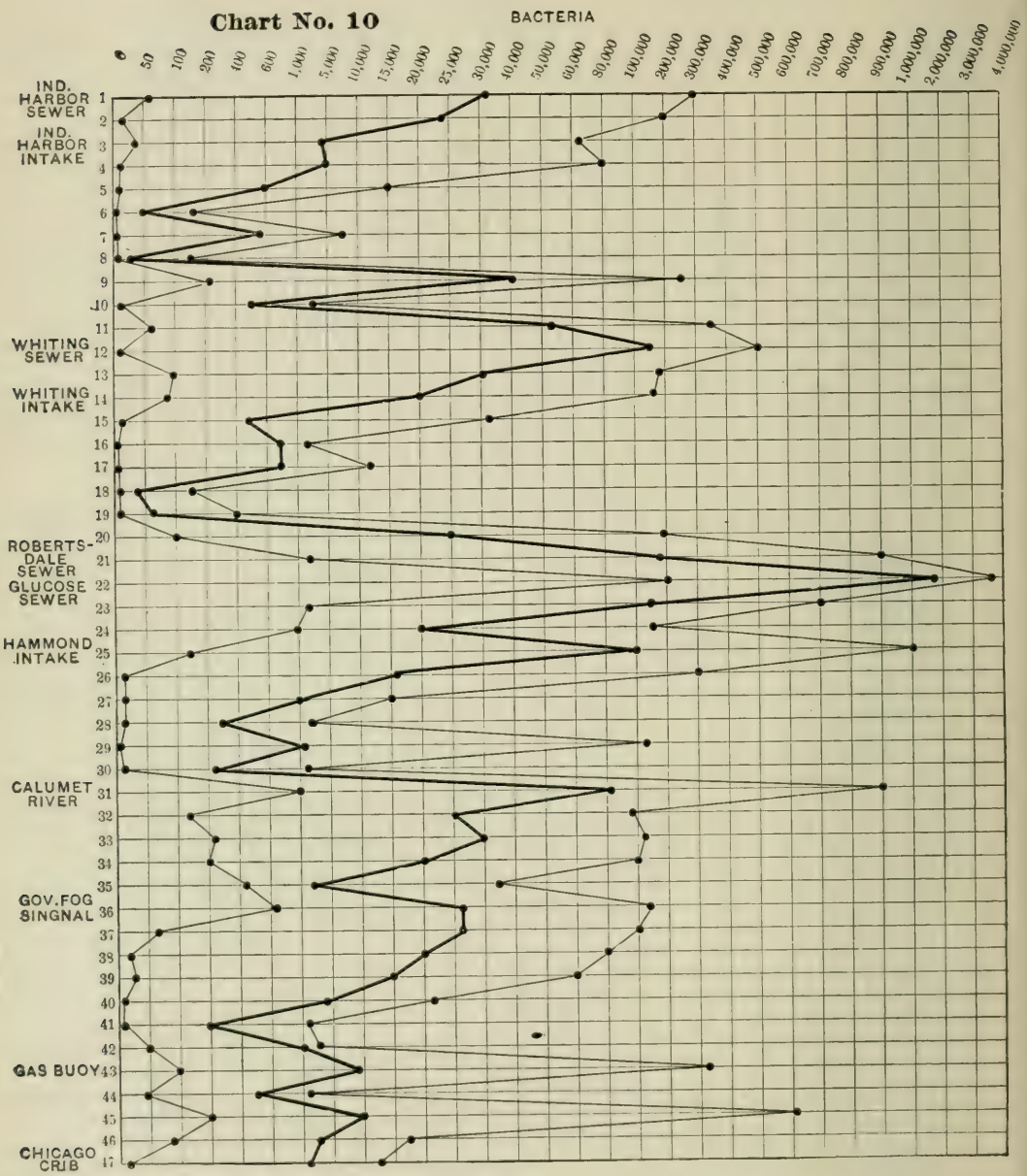


Chart No. 10
BACTERIA
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4,000,000
IND. HARBOR SEWER
IND. HARBOR INTAKE
WHITING SEWER
WHITING INTAKE
ROBERTS-DALE SEWER
GLUCOSE SEWER
HAMMOND INTAKE
CALUMET RIVER
GOV. FOG SINGNAL
GAS BUOY
CHICAGO CRIB
1
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longer afford to pollute it and to destroy it as a water supply. The discharge of all unpurified sewage or industrial wastes into the lake must be stopped and the former purity of the water regained.

No single municipality can hope adequately to handle the situation. The problem of a purified and permanently potable Lake Michigan can only be solved by the concerted efforts of every city on its southern shore, aided by the joint action of the States of Illinois and Indiana.

Recommendations.

As the result of the study of the pollution of Lake Michigan and the condition of the public water supplies of the cities of Hammond, East Chicago and Whiting, we suggest the following possible means by which the situation may be remedied:

(1) The installation of gravity or mechanical filters to purify the water of each of the present systems.

(2) The installation of sewage disposal plants to purify the sewage or otherwise destroy the injurious bacteria now being poured into the lake.

(3) Such action as will stop permanently the dumping of dredged material within five miles of any water intake.

(4) The abatement of the nuisance known as the Glucose sewer.

(5) The abandonment of the lakes as source of water supply and the use of deep well water, undoubtedly to be found in sufficient abundance for present needs.

(6) The opening of a channel to the Illinois River to convey all sewage away from the lake.

The first proposal or the installation of purification plants is obviously not to be considered because of the cost of constructing and maintaining purification plants for a series of independent cities, and the greatly increased population that will soon occupy the entire lake front. It is furthermore not practicable to pollute a naturally pure water and then by artificial methods to remove the contaminating material.

The second proposal, or the installation of sewage disposal plants, is equally unsatisfactory. While it is possible to purify sewage to such an extent that it is not disease producing, it is not possible so to treat manufacturing wastes that they will not increase the mineral constituents of the water. Moreover, while it is better to drink filtered than raw sewage, both practices are repellant and to be avoided if possible.

The third proposal, to stop the dumping of dredged material into the lake, is entirely feasible and should at once be carried out. This is also true of the fourth suggestion, which is the abatement of the Glucose sewer.

The fifth suggestion, that the lake be abandoned and a water supply sought elsewhere, is not tenable. No necessity should be so great as to require the abandonment of one of the largest bodies of potable water in the world and in its place the installation of a deep well system of doubtful adequacy.

The last proposal, which is the opening of a channel to the Illinois River, is the most feasible and undoubtedly the most practicable. If the necessary Federal and State permission can be secured to allow the carriage of sewage across the line into an adjoining State, it is probable that the engineering problems can be solved. Some such action is the more necessary, because the city of South Chicago and the Illinois population now sewering into the Calumet must act with the Indiana cities if the pollution of the lake is to be stopped.

Whatever action is taken either to dispose of sewage or to obtain a pure water supply, must be undertaken jointly by all the cities interested. To this end legislation authorizing the establishment of a sanitary district is advisable, and is suggested as the first step toward the betterment of civic sanitary conditions of Lake County.

DISCUSSION.

MEMBER: "What time intervened between the taking or drawing of the sample and making the tests?"

MR. BREWSTER: "I think that the maximum time could be stated as three hours. After the sample was taken it was placed in an ice box until the test was made. In this way a change in the bacterial counts was prevented from the time the sample was taken until the test was made."

MEMBER: "The result was so important that it would be necessary to keep the sample in its original state."

DR. JAMES: "I would like to ask Mr. Brewster the present state of the Chicago Drainage Canal with reference to the disposal of the sewage of the city of Chicago?"

MR. BREWSTER: "The Chicago Drainage Canal takes care of the greater part of the drainage of Chicago, but the sewage of South Chicago enters the Calumet River."

MEMBER: "What number of bacteria would you consider to be reasonably safe for a water supply?"

MR. BREWSTER: "The water of Lake Michigan in its original state is absolutely sterile—in any case, not over two or three bacteria per c.c., and most of the time giving absolutely sterile plates. At Michigan City a similar work was done and practically sterile water was found at a distance only one mile from shore."

MEMBER: "What medium was used for the test?"

MR. BREWSTER: "Nutrient gelatine was used for the bacterial counts, the incubation being at 20° C., and dextrose broth in fermentation tubes incubated at 38° C. for the test of B. Coli."

THE FERRIC IRON CONTACT PROCESS OF MAKING SULPHURIC ACID FROM SMELTER SMOKE

By

THORN SMITH

The Ducktown Sulphur Copper and Iron Co., of Isabella, Tenn., has been for the past five years and more conducting experiments with a view to finding means of eliminating the sulphur dioxide fumes resulting from the smelting of heavy copper sulphide ores. Early in the work it became evident that nothing short of the manufacture of sulphuric acid would solve the problem economically. Experiments were therefore conducted in that direction. The almost complete absence of arsenic and other platinum poisons justified the belief that the platinum process was best adapted to existing conditions. Results obtained in experimental work, using the actual smelter fumes, were highly satisfactory. Later, owing to a possible future change in the composition of the ore, it was decided that a combination of the iron and platinum processes offered better advantages.

At first, caution being advisable, a 10-ton plant using the ferric oxide process alone was contracted for, leaving the installation of the platinum addition until such a time as the ferric process had demonstrated its capabilities. Assurance was given by the designer of the plant that a conversion of at least 50 per cent. could be maintained, and this without a preliminary drying of the smelter gases.

The temperature of the gases as they entered the acid system averaged about 1,000° C., and by means of a so-called equalizer, constructed of fire-brick, it was expected that a sufficiently high temperature could be maintained without any additional heating of the gases before conversion. The equalizer was followed by a series of ordinary pyrite burners, slightly modified to meet the conditions imposed. The rest of the apparatus was probably not far different from the ordinary forms used in this process.

It is not the purpose of this article to criticise the design or construction of the plant, hence I shall abstain as much as possible in this direction. However, it was immediately evident that with a 50

per cent. conversion, coupled with the fact that the rainfall in this vicinity is the heaviest in the United States and consequently that the humidity is high, 100 per cent. acid could not be made as promised by the designer. In fact, that unless the conversion was maintained at a point considerably in excess of 50 per cent., the resulting acid would be very much weaker.

The plan of operation was to deflect, by means of fans at the end of the acid system, sufficient gas from the dust chamber of the smelting plant to make the required 10 tons of 100 per cent. acid. The gas passed first through the equalizer, previously mentioned, then through the several burners containing burning sulphur ore. These burners were installed for the purpose of enriching the gas and at the same time serving as a filter for the greater part of the dust. It was assumed, without justification, that the zinc oxide, a constituent of the dust, was volatile and would not collect on the ore in the burners or on the iron oxide in the contact chamber. But a few days of operation were necessary to show that the zinc oxide would collect on and coat every portion of the plant from end to end, and more particularly the contact-mass, owing to its large area and the consequently slower movement of the gas.

It was early evident that the contact action was far below 50 per cent., simply because the total yield of acid was extremely low. It was impossible to ascertain the conversion even approximately owing to the location of the fans at the end of the system, which caused an inrush of extraneous air at every possible opening, let alone that due to the frequent opening of the burner doors for charging. The very low conversion, together with the fact that the gases carried their normal atmospheric moisture and also a considerable additional amount from the moist ore of the smelting furnace, made an extremely weak acid, which, as soon as condensed, attacked the iron parts of the plant, causing excessive damage.

Efforts were continued to overcome the manifest difficulties. Opinions differed as to why the yield was so extremely low. All the doors and the spent oxide shaken from the contact chamber were densely coated with zinc oxide or its resultant salts formed in such an atmosphere. Eventually the iron oxide in the contact chamber became so clogged with the zinc oxide, or to be more exact, with a dry, fine white zinc sulphate, that the contact mass had to be removed and fresh material added in large excess of what would ordinarily have been required in the daily working of the plant.

After several weeks of continued effort to make a quantity of acid approaching 10 tons and almost daily additions of fresh contact material, the entire plant was placed in my hands, with instructions to do the best I could until a decision could be reached as to future action. I believed the chief troubles from a chemical standpoint to be the presence of the zinc salts and the use of moist gas. I therefore conducted a series of experiments, using an ordinary combustion tube 30 inches long by 1 inch in diameter, wrapped with resistance wire and heated by means of an electric current. The temperature was easily controlled by external resistance. The temperature of the contact mass was observed by means of a pyrometer which was frequently checked by a thermometer. No greater variation than 10° plus or minus was at any time observed in reading the pyrometer.

Experiment A.

To determine the conversion factor of the moist gas. Conducted with a contact mass of well-roasted pyrite, a slow current of gas (approximately 2,000 cubic centimeters per minute), undried, but thoroughly cleaned by bubbling through water and filtering through asbestos.

		Conversion		
Centigrade Temperature.	No. of Tests.	Maximum, Per Cent.	Minimum, Per Cent.	Average, Per Cent.
605	3	37.8	31.9	34.1
610	4	42.6	39.9	41.0
615	6	44.0	42.4	43.2
620	12	43.9	39.0	41.5
625	3	41.5	40.6	41.1
630	2	42.6	42.6	42.6
635	5	39.7	35.6	37.7
640	3	37.9	35.7	37.2

The highest average conversion obtained was 43.2 per cent. at about 615°.

Experiment B.

To determine the conversion factor of dry gas. Conducted with a contact mass of the same nature as used in A. The gas was thoroughly dried and filtered before passing through the contact mass. The speed of the gas was the same as in A.

Centigrade Temperature.	No. of Tests.	Conversion Maximum, Per Cent.	Conversion Minimum, Per Cent.	Conversion Average, Per Cent.
580	3	29.9	26.3	27.5
585	2	34.7	31.3	33.0
595	1	....	....	48.4
605	1	....	....	49.6
610	6	51.7	49.5	51.0

The highest average conversion of 51.0 per cent. was obtained at about 610°. Further work may have given higher results, but lack of time prevented, and besides the point in question was satisfactorily demonstrated.

EXPERIMENT C.

To determine as nearly as experiment would permit the possibilities of the 10-ton plant under discussion. Conducted with well-roasted pyrite coated with the zinc salt deposited in the contact chamber of the large plant, together with undried but filtered furnace gas. As the velocity of the gas has a very appreciable effect on the rate of conversion, three experiments were made in which the velocity of the gas was varied.

C. 1. Flow about 1,000 c.c. per minute.

Centigrade Temperature.	No. of Tests.	Conversion Maximum, Per Cent.	Conversion Minimum, Per Cent.	Conversion Average, Per Cent.
580	1	....	....	23.3
590	4	25.9	21.8	23.3
610	1	....	....	28.6
615	6	29.9	23.3	27.1
620	5	41.7	31.0	34.8
625	1	....	....	36.7
630	2	31.0	30.7	30.9
640	1	....	....	35.1

C. 2. Flow about 2,000 c.c. per minute.

Centigrade Temperature.	No. of Tests.	Conversion Maximum, Per Cent.	Conversion Minimum, Per Cent.	Conversion Average, Per Cent.
585	2	26.8	24.2	25.5
590	7	25.2	19.5	22.3
595	2	31.4	20.3	25.9
600	4	25.9	23.2	24.5
610	2	23.9	22.1	23.0
615	1	....	....	24.5
620	32	33.9	20.7	27.5
625	2	31.4	31.4	31.4
630	4	32.6	23.3	27.7

C. 3. Flow about 3,000 c.c. per minute.

Centigrade Temperature.	No. of Tests.	Conversion—Maximum, Per Cent.	Conversion—Minimum, Per Cent.	Conversion—Average, Per Cent.
530	1	....	....	9.1
535	1	....	....	8.5
540	1	....	....	9.5
570	1	....	....	5.8
580	1	....	....	15.5
590	2	18.5	16.1	17.3
595	1	....	....	14.5
600	2	15.5	12.1	13.8
610	5	17.3	15.5	16.5
620	14	24.6	20.4	22.2
625	1	....	....	25.9
640	2	18.1	17.7	17.9

In experiment C 1 the maximum average was 36.7 per cent. A few tests with a much slower current gave no higher figures.

In experiment C 2, with about the same speeds as in A and B, the maximum average conversion was 31.4 per cent., a material drop from that obtained in C 1.

In experiment C 3 the maximum average conversion was 25.9 per cent., a still further drop.

It is apparent from these last three experiments, when compared with results obtained in A and B, that the zinc dust caused a material reduction in the rate of conversion. As the contact material was of the same nature throughout, it is very evident that the zinc salts have a retarding influence. As this was practically the only dust that reached the contact chamber, the trouble could not be ascribed to anything else.

To cool the smelter gas, then to filter it to remove the zinc dust and again heat it to the required conversion temperature meant the expenditure of a good many thousand dollars. To further dry the gas in addition to the above would cause a still larger expenditure and a practical rebuilding of the entire plant. For these reasons, together with the fact that all parts of the apparatus following the contact chamber were in an extremely bad condition owing to the action of the dilute acid on the iron parts, it was finally decided to abandon the whole undertaking.

The experimental work outlined above was for the purpose of obtaining comparative results. Lengthening the contact mass, using

richer or weaker gas, and a number of other alterations may have increased the conversion.

The experiments, however, confirm the generally accepted belief that the action of contact bodies is retarded by anything which modifies their active surface. For the present there is nothing which justifies any expectations whatever of success for contact processes applied directly to smelter fumes containing such volatile ingredients as zinc, probably lead, and other metals, excepting, of course, arsenic. Flue dust which may be nothing more than finely divided ore would probably have little or no effect unless present in abnormal amounts.

It may be of interest to add that an extremely large chamber plant is now under rapid construction and no trouble is anticipated in its operation.

CALCULATIONS FOR DRYER DESIGN

By

WILLIAM M. GROSVENOR

Permit a preliminary word about the calculations embodied in the few lines before you. More than 3,000 are necessarily involved, to say nothing of the trial curves plotted and discarded as unsatisfactory. One interesting point should be mentioned. Much of the checking and some of the calculations were done by the slide rule and it was found that, using an ordinary 20 in. Faber rule with a jewellers' glass, results of surprising accuracy could be obtained. Exact checks of four figures frequently occurred. In this way the slide rule can be relied on to 1 part in 1,500. Recollecting that most atomic weights are questionable to this extent and that analytical results are generally worthless in the fourth place, it is surprising that the slide rule is not more universally used and facility with it required of every chemical and engineering student. We strain at the gnat and swallow the camel; calculating discounts to 1 cent in $1,000.00 on a carload of goods that we have not weighed within 50 lbs. or 1 in 800.

The following methods were developed as a matter of commercial necessity. They were needed to design a great number of drying installations adapted to meet widely different requirements, operating under a system, the advantages of which have hitherto been largely overlooked, i. e., the repeated circulation of the same air over condensing coils to remove moisture, over heating pipes to increase the "moisture capacity," over the material being dried and again over the condenser. Surprising steam economies are thus accomplished, in some cases amounting to more than 80 per cent. Insurance risks are reduced. So-called "moist drying" becomes a matter of course, great capacity is permitted and complete independence of climatic conditions makes accurate design and perfect regulation possible. So we had an almost virgin field and tried to follow the excellent advice of Mr. Walter C. Kerr to the graduating engineers, "——, go as far as you can see and then see how far you can go."

The engineering of drying is to-day one of the most neglected and by no means one of the most simple branches of applied science.

There are thousands of installations where the air travels 10 ft. in idleness to one of useful occupation, where it is taken from the streets and the gutters and blown loaded with bacteria over fermentive products (many of them food stuffs), where it is received ice cold and heated up 50° or 100° before it begins to do its profitable work, or is drawn in nearly saturated at 85° to dry a product that cannot safely be heated above 95°, where, worst of all, it is expected to reverse the performance of the widow's oil jug, and to keep on drinking up moisture indefinitely without renewal or dehydration. Taking advantage of the variable weather conditions, which the seller of machinery had no object in controlling, the machinery was made big enough—the bigger the better.

In developing simple, rapid and, at the same time, reasonably accurate methods of design, we were met at once with the fundamental difficulty that there is no simple equation giving the relation between the tension of aqueous vapor and the amount of water (either by volume or weight) saturating air under given conditions. The next difficulty was that the base or divisor (cubic foot) of all humidity calculations has hitherto been most unfortunately selected; as it varies with every change of pressure, temperature, or humidity, needlessly complicating all calculations. Lastly, that "percentage humidity," more properly called "degree of humidity," is not really comparable percentage at all. Ten per cent. of humidity means that 1 cu. ft. of mixture contains one-tenth the amount of water which a cubic foot of another mixture containing less air would carry if saturated under the same conditions of temperature and pressure.

While such a standard of humidity may be satisfactory for meteorological records, practical design in a field thus obstructed was a dangerous thing to turn over to subordinates, and it seemed advisable to begin by getting rid of stumpage and doing some grading. Finally there was marked disagreement in published tables of the essential constants*

The last question was first taken up. The original sources were examined and an entirely new set of calculations made from vapor tensions to weight of water per cubic foot, using the following formulæ and constants:

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* "Drying by Air and Steam," E. Hausbrandt, '01, pp. 10, 11.
"Weights of Air, Vapour of Water, etc.," Kent's Mechanical Engineer's Pocketbook, pp. 484.
"Psychrometric Tables," W. B. No. 235, Prof. C. F. Marvin, Government Print, 1900.
"Chem. Kalendar," Beilage, pp. 87.
"Phys.-Chem. Tabellen," Landolt & Boernstein, 1894, pp. 13, 53, 63, 64.

$$\text{Density of Air} + .04\%\ CO_2 = \frac{1.293052}{1 + .00367 \times \text{Temp. C.}} \text{ (in kg. per cu. m.).}$$

$$\text{Density of Water Vapor} = .62186 \times \text{Density of Air.}$$

$$\frac{\text{Density at Partial Press.}}{\text{Density at 760 mm.}} = \frac{\text{Partial Press. in mm.}}{760}$$

$$\text{Wt. in kg. of 1 cu. m. of residual air} = \frac{\text{par. press.}}{760} \times \text{density of air (in kg. per cu. m.).}$$

$$\left.\begin{array}{l}\text{Wt. in kg. of 1 cu. m. of} \\ \text{water vapor at partial press.}\end{array}\right\} = \frac{.62186\,\text{par. press.}}{760} \times \text{density of air.}$$

Specific Heat water vapor = .475. Specific Heat air = .2373.

Kg. per cu. m. × .062428 = lbs. per cu. ft.

Results of these calculations are given for every degree centigrade in Table Ia, and for every degree Fahrenheit interpolated for 1a in Table Ib.

These results (Col. 9, Table Ia,* and Col. 3, Table Ib) differed as much as 4% from the various published figures, but showed a surprising agreement ($\frac{1}{4}$% due to allowance for .04% CO_2 in air) with the figures of the United States Weather Bureau. The reason for this was inquired into. Quoting from the Psychrometric Tables of the United States Weather Bureau of 1900 (prepared by Dr. C. F. Marvin, Professor of Meteorology), it will be seen how carefully the Weather Bureau's tables were prepared:

"The vapor pressures employed were derived from Broch's reduction of Regnault's observations. All the values given by these tables at temperatures below the freezing point are noticeably higher than Regnault's observations. In view of this systematic discordance and the further circumstance that Regnault's experiments did not include observations at the extremely low temperatures frequently recorded at Weather Bureau stations, the writer (Dr. Marvin) in 1891, made a new determination of the maximum pressure of aqueous vapor at low temperatures.

"In the course of these experiments it was found an easy matter to reduce the temperature of the water employed many degrees below 32° F., without freezing it, and in these cases the vapor pressure was higher than the pressure from ice at the same temperature. Independent experiments in Sweden, by Julius Johlin, at about this time, led to the same results.

*This table may be found in the pocket in the back cover of this volume.

HUMIDITY TABLE

TABLE 1 b

Temp. F.	Vapor Tension in Millimeters	Lbs. Water Vapor per Pound Air	Humid Heat in B. T. U.	Humid Volume in cu. ft.	Density in lbs. per cu. ft. @ 760 Millimeters Dry Air.	Density in lbs. per cu. ft. @ 760 Millimeters Sat'd Mix.	Specific Volume in cu. ft. per lb. of Dry Air.	Specific Volume in cu. ft. per lb. of Sat'd Mix.
1	2	3	4	5	6	7	8	9
32	4.569	.0037611	.2391	12.462	.080726	.080556	12.388	12.414
33	4.746	.0039176	.2392	12.491	.080559	.080377	12.413	12.442
34	4.949	.0040763	.2392	12.521	.080393	.080198	12.439	12.469
35	5.151	.0042435	.2393	12.549	.080231	.080025	12.464	12.496
36	5.358	.0044151	.2394	12.578	.080069	.079852	12.489	12.523
37	5.572	.0045931	.2395	12.606	.079910	.079680	12.514	12.549
38	5.795	.0047781	.2396	12.636	.079748	.079511	12.539	12.576
39	6.023	.0049679	.2397	12.666	.079585	.079343	12.565	12.604
40	6.264	.0051678	.2398	12.695	.079428	.079177	12.590	12.629
41	6.507	.0053703	.2399	12.724	.079272	.079012	12.615	12.655
42	6.765	.0055850	.2400	12.754	.079113	.078845	12.640	12.682
43	7.026	.0058026	.2400	12.784	.078954	.078677	12.666	12.710
44	7.301	.0060320	.2401	12.813	.078797	.078514	12.692	12.736
45	7.583	.0062670	.2403	12.843	.078641	.078348	12.718	12.763
46	7.874	.0065103	.2404	12.872	.078485	.078178	12.741	12.791
47	8.177	.0067640	.2405	12.904	.078329	.078010	12.766	12.819
48	8.486	.0070239	.2407	12.935	.078172	.077844	12.792	12.846
49	8.811	.0072942	.2408	12.968	.078019	.077678	12.817	12.874
50	9.140	.0075697	.2409	12.999	.077867	.077511	12.842	12.901
51	9.488	.0078620	.2410	13.030	.077714	.077344	12.868	12.927
52	9.841	.0081579	.2411	13.062	.077562	.077178	12.893	12.957
53	10.210	.0084683	.2413	13.095	.077409	.077016	12.919	12.984
54	10.589	.0087865	.2415	13.127	.077258	.076851	12.944	13.012
55	10.980	.0091163	.2416	13.159	.077109	.076685	12.968	13.041
56	11.386	.0094581	.2418	13.192	.076959	.076522	12.993	13.068
57	11.801	.0098064	.2420	13.224	.076810	.076363	13.019	13.096
58	12.235	.010165	.2421	13.258	.076661	.076198	13.044	13.124
59	12.674	.010546	.2423	13.292	.076512	.076032	13.070	13.152
60	13.138	.010939	.2425	13.326	.076363	.075865	13.095	13.180
61	13.608	.011338	.2427	13.360	.076215	.075698	13.121	13.210
62	14.100	.011755	.2429	13.395	.076069	.075529	13.146	13.240
63	14.603	.012183	.2431	13.431	.075924	.075362	13.171	13.270
64	15.122	.012625	.2433	13.467	.075779	.075198	13.196	13.298
65	15.660	.013083	.2435	13.501	.075635	.075039	13.222	13.325
66	16.209	.013552	.2438	13.538	.075493	.074882	13.246	13.354
67	16.783	.014043	.2440	13.573	.075349	.074718	13.272	13.384
68	17.363	.014539	.2442	13.609	.075206	.074552	13.298	13.413
69	17.975	.015065	.2444	13.645	.075062	.074387	13.323	13.441
70	18.595	.015597	.2447	13.683	.074921	.074219	13.348	13.471
71	19.242	.016154	.2450	13.720	.074778	.074054	13.373	13.502
72	19.903	.016724	.2452	13.759	.074636	.073899	13.398	13.532
73	20.585	.017312	.2455	13.797	.074496	.073735	13.424	13.562
74	21.289	.017922	.2458	13.837	.074357	.073570	13.449	13.593
75	22.008	.018545	.2461	13.876	.074218	.073405	13.474	13.624

HUMIDITY TABLE—(Cont'd).

TABLE 1 b

Temp. F.	Vapor Tension in Millimeters	Lbs. Water Vapor per Pound Air	Humid Heat in B. T. U.	Humid Volume in cu. ft.	Density in lbs. per cu. ft. @ 760 Millimeters		Specific Volume in cu. ft. per lb. of	
					Dry Air.	Sat'd Mix.	Dry Air.	Sat'd Mix.
1	2	3	4	5	6	7	8	9
76	22.759	.019198	.2464	13.916	.074079	.073239	13.499	13.654
77	23.517	.019857	.2467	13.956	.073940	.073072	13.524	13.685
78	24.316	.020554	.2470	13.997	.073801	.072909	13.549	13.715
79	25.124	.021260	.2474	14.039	.073663	.072747	13.575	13.746
80	25.965	.021998	.2478	14.081	.073529	.072585	13.600	13.777
81	26.724	.022752	.2481	14.123	.073395	.072419	13.625	13.809
82	27.711	.023532	.2485	14.167	.073258	.072248	13.650	13.841
83	28.625	.024339	.2488	14.211	.073123	.072080	13.675	13.873
84	29.557	.025164	.2492	14.255	.072987	.071913	13.701	13.906
85	30.529	.026026	.2497	14.301	.072852	.071744	13.726	13.938
86	31.510	.026898	.2501	14.347	.072716	.071574	13.752	13.971
87	32.541	.027819	.2505	14.394	.072584	.071404	13.776	14.004
88	33.582	.028750	.2510	14.442	.072453	.071234	13.801	14.038
89	34.667	.029723	.2514	14.490	.072321	.071064	13.827	14.072
90	35.774	.030718	.2519	14.539	.072189	.070894	13.852	14.106
91	36.913	.031747	.2524	14.588	.072058	.070724	13.787	14.139
92	38.087	.032810	.2529	14.638	.071926	.070556	13.903	14.173
93	39.283	.033896	.2534	14.688	.071794	.070390	13.929	14.206
94	40.528	.035029	.2539	14.740	.071664	.070221	13.954	14.241
95	41.784	.036174	.2545	14.793	.071535	.070051	13.979	14.275
96	43.102	.037388	.2550	14.846	.071407	.069878	14.004	14.310
97	44.436	.038603	.2556	14.900	.071279	.069704	14.030	14.346
98	45.824	.039817	.2562	14.956	.071149	.069530	14.055	14.582
99	47.228	.041206	.2569	15.013	.071021	.069356	14.080	14.419
100	48.679	.042557	.2575	15.071	.070894	.069179	14.106	14.455
101	50.171	.043955	.2582	15.131	.070767	.069002	14.131	14.492
102	51.691	.045382	.2589	15.192	.070641	.068825	14.155	14.530
103	53.271	.046876	.2596	15.253	.070516	.068645	14.181	14.568
104	54.865	.048385	.2603	15.313	.070390	.068464	14.207	14.606
105	56.534	.049974	.2610	15.376	.070265	.068288	14.232	14.643
106	58.219	.051583	.2618	15.440	.070141	.068110	14.257	14.682
107	59.968	.053268	.2626	15.506	.070018	.067926	14.282	14.722
108	61.749	.054996	.2634	15.572	.069894	.067745	14.307	14.761
109	63.578	.056634	.2643	15.640	.069771	.067568	14.333	14.800
110	65.459	.058613	.2651	15.711	.069647	.067383	14.358	14.840
111	67.374	.060492	.2660	15.783	.069525	.067192	14.384	14.883
112	69.359	.062456	.2670	15.856	.069403	.067007	14.409	14.924
113	71.362	.064442	.2679	15.930	.069281	.066823	14.434	14.965
114	73.455	.066540	.2689	16.006	.069160	.066636	14.459	15.008
115	75.569	.068663	.2699	16.084	.069040	.066448	14.484	15.050
116	77.757	.070881	.2710	16.164	.068920	.066257	14.509	15.094
117	79.986	.073150	.2720	16.245	.068800	.066064	14.535	15.137
118	82.273	.075514	.2732	16.328	.068681	.065871	14.560	15.179
119	84.621	.077921	.2743	16.413	.068562	.065675	14.585	15.225
120	87.010	.080403	.2755	16.499	.068443	.065477	14.611	15.272

HUMIDITY TABLE—(Cont'd).

TABLE 1 b

Temp. F	Vapor Tension in Millimeters	Lbs. Water Vapor per Pound Air	Humid Heat in B. T. U.	Humid Volume in cu. ft.	Density in lbs. per cu. ft. @ 760 Millimeters Dry Air.	Density in lbs. per cu. ft. @ 760 Millimeters Sat'd Mix.	Specific Volume in cu. ft. per lb. of Dry Air.	Specific Volume in cu. ft. per lb. of Sat'd Mix.
1	2	3	4	5	6	7	8	9
121	89.484	.082998	.2767	16.589	.068325	.065280	14.636	15.319
122	91.978	.085622	.2780	16.679	.068207	.065082	14.661	15.365
123	94.581	.088399	.2793	16.774	.068090	.064884	14.686	15.412
124	97.207	.091208	.2806	16.870	.067973	.064681	14.711	15.460
125	99.924	.094147	.2820	16.968	.067857	.064479	14.736	15.509
126	102.686	.09716	.2835	17.069	067741	.064277	14.762	15.558
127	105.518	.10027	.2849	17.172	.067625	.064075	14.788	15.606
128	108.428	.10350	.2864	17.278	.067510	.063870	14.813	15.657
129	111.382	.10680	.2880	17.386	.067394	.063663	14.838	15.708
130	114.437	.11022	.2896	17.499	.067280	.063451	14.863	15.761
131	117.516	.11368	.2913	17.612	.067166	.063239	14.888	15.814
132	120.724	.11742	.2931	17.730	.067052	.063025	14.914	15.867
133	123.960	.12121	.2949	17.851	.066938	.062810	14.939	15.921
134	127.304	.12514	.2968	17.976	.066826	.062593	14.964	15.977
135	130.702	.12917	.2987	18.103	.066713	.062376	14.989	16.032
136	134.182	.13335	.3006	18.235	.066601	.062159	15.015	16.087
137	137.749	.13768	.3026	18.370	.066489	.061939	15.040	16.145
138	141.372	.14122	.3047	18.508	.066377	.061717	15.065	16.204
139	145.114	.14678	.3070	18.653	.066267	.061487	15.090	16.264
140	148.885	.15150	.3093	18.800	.066156	.061255	15.116	16.325
141	152.807	.15652	.3117	18.952	.066045	.061022	15.141	16.387
142	156.762	.16161	.3141	19.108	.065935	.060789	15.166	16.450
143	160.841	.16696	.3166	19.270	.065823	.060554	15.192	16.512
144	164.986	.17245	.3192	19.437	.065712	.060318	15.217	16.576
145	169.227	.17816	.3219	19.609	.065606	.060082	15.242	16.643
146	173.569	.18409	.3247	19.787	.065498	.060842	15.267	16.711
147	177.976	.19017	.3276	19.971	.065390	.060599	15.293	16.780
148	182.522	.19659	.3307	20.161	.065283	.060353	15.318	16.848
149	187.103	.20310	.3338	20.354	.065176	.059106	15.343	16.919
150	191.860	.21005	.3371	20.559	.065068	.058865	15.368	16.993
151	196.654	.21710	.3404	20.767	.064962	.058605	15.394	17.068
152	201.595	.22455	.3440	20.987	.064856	.058349	15.419	17.141
153	206.610	.23221	.3476	21.211	.064750	.058092	15.444	17.215
154	211.739	.24020	.3514	21.445	.064644	.057833	15.469	17.291
155	216.983	.24854	.3553	21.687	.064539	.057570	15.494	17.370
156	222.305	.25713	.3594	21.936	.064433	.057305	15.520	17.450
157	227.786	.26623	.3637	22.201	.064328	.057036	15.545	17.533
158	233.308	.27546	.3681	22.468	.064224	.056767	15.570	17.616
159	239.034	.28542	.3728	22.754	.064120	.056493	15.596	17.701
160	244.803	.29554	.3776	23.045	.064016	.056218	15.621	17.788
161	250.742	.30624	.3827	23.352	.063913	.055938	15.646	17.877
162	256.767	.31737	.3880	23.670	.063810	.055656	15.671	17.968
163	262.923	.32901	.3936	24.001	.063707	.055372	15.697	18.060
164	269.213	.34123	.3994	24.349	.063605	.055084	15.722	18.154
165	275.592	.35385	.4054	24.708	.063502	.054795	15.748	18.250

HUMIDITY TABLE—(Cont'd).

TABLE 1 b

Temp. F.	Vapor Tension in Millimeters	Lbs. Water Vapor per Pound Air	Humid Heat in B. T. U.	Humid Volume in cu. ft.	Density in lbs. per cu. ft. @ 760 Millimeters		Specific Volume in cu. ft. per lb. of	
					Dry Air.	Sat'd Mix.	Dry Air.	Sat'd Mix
1	2	3	4	5	6	7	8	9
166	282.155	.36734	.4118	25.090	.063400	.054500	15.772	18.349
167	288.764	.38106	.4183	25.478	.063298	.054203	15.798	18.449
168	295.609	.39602	.4254	25.900	.063198	.053901	15.823	18.551
169	302.504	.41126	.4327	26.330	.063098	.053598	15.848	18.654
170	309.593	.42762	.4405	26.790	.062997	.053292	15.874	18.764
171	316.781	.44462	.4485	27.267	.062897	.052983	15.899	18.875
172	324.120	.46257	.4570	27.768	.062799	.052670	15.924	18.986
173	331.612	.48162	.4660	28.301	.062699	.052353	15.949	19.101
174	339.207	.50140	.4754	28.855	.062599	.052032	15.975	19.219
175	347.015	.52285	.4856	29.454	.062500	.051708	16.000	19.339
176	354.873	.54472	.4960	30.063	.063402	.051382	16.025	19.462
177	363.003	.56901	.5076	30.738	.062304	.051049	16.050	19.589
178	371.190	.59386	.5194	31.428	.062207	.050715	16.076	19.719
179	379.598	.62097	.5322	32.180	.062112	.050378	16.101	19.851
180	388.121	.64942	.5458	32.967	.062015	.050038	16.126	19.987
181	396.815	.67985	.5602	33.810	.061915	.049693	16.152	20.126
182	405.686	.71265	.5758	34.717	.061816	.049342	16.177	20.269
183	414.674	.74703	.5921	35.666	.061719	.048988	16.202	20.415
184	423.904	.78519	.6102	36.718	.061623	.048628	16.227	20.566
185	433.194	.82430	.6288	37.796	.061529	.048265	16.253	20.719
186	442.793	.86911	.6501	39.029	.061434	.047898	16.278	20.879
187	452.456	.91535	.6721	40.302	.061339	.047529	16.303	21.041
188	462.374	.96731	.6967	41.729	.061244	.047153	16.328	21.209
189	472.422	1.0227	.7230	43.251	.061149	.046774	16.353	21.381
190	482.668	1.0835	.7519	44.918	.061053	.046391	16.379	21.557
191	493.111	1.1510	.7843	46.768	.060961	.046003	16.404	21.739
192	503.690	1.2230	.8190	48.739	.060867	.045611	16.429	21.925
193	514.545	1.3067	.8579	51.021	.060774	.045213	16.454	22.119
194	525.468	1.3933	.8990	53.402	.060681	.044813	16.480	22.315
195	536.744	1.4994	.9494	56.302	.060588	.044405	16.505	22.522
196	548.093	1.6108	1.0023	59.349	.060496	.043997	16.530	22.730
197	559.731	1.7436	1.0714	62.978	.060403	.043586	16.556	22.945
198	571.519	1.8917	1.1358	67.024	.060311	.043169	16.581	23.166
199	583.531	2.0629	1.2171	71.696	.060219	.042742	16.606	23.398
200	595.768	2.2684	1.3147	77.304	.060127	.042308	16.631	23.638
201	608.155	2.4968	1.4231	83.537	.060036	.041868	16.656	23.886
202	620.871	2.7987	1.5665	91.768	.059946	.041425	16.682	24.142
203	633.657	3.1189	1.7186	100.499	.059855	.040982	16.707	24.401
204	646.845	3.6512	1.9159	115.210	.059764	.040530	16.732	24.675
205	660.116	4.2272	2.1562	131.028	.059674	.040075	16.758	24.954
206	673.718	4.9776	2.5681	151.272	.059585	.039610	16.783	25.248
207	687.489	6.0699	3.1238	180.906	.059495	.039143	16.808	25.549
208	701.516	7.6748	3.8948	224.623	.059406	.038673	16.834	25.860
209	715.805	11.1295	6.2569	362.091	.059317	.038049	16.858	26.289
210	730.267	15.8174	15.9148	562.054	.059228	.037323	16.884	26.796
211								
212								

"A comparison of the vapor pressures derived from the several sources mentioned shows that Broch's computed values at low temperatures do not agree at all well with Regnault's experiments, from which they are derived, whereas the experimental results of Regnault, Johlin and the writer (Dr. Marvin) agree very closely.

"At temperatures below 32° F., therefore, it has been considered necessary to reject Broch's values, and the vapor pressures over ice, as deduced from the writer's experiments, have been used in the calculation of the tables. At temperatures above 32° F., the values taken from Broch's tables are employed. At 32° F., the value for the vapor pressure found by the writer from the mean of a large number of experiments was identical with that of Broch; hence there is no break in the continuity of the two tables at the point of junction."

The calculated weight of water per lb. of air does not agree with actual determinations, but shows progressive differences, possibly owing to association of molecules in the vapor, too small in magnitude, however, to affect our present purpose.

Regarding this difference, Dr. Marvin writes me:

"In all ordinary computations it is assumed that the expansion and contraction of partially saturated aqueous vapor is in accordance with the same laws as apply to air and ordinary gases, which do not easily condense to the liquid state.

"The adopted density of saturated aqueous vapor is not determined directly from experiment, but is deduced theoretically from the observed fact that two volumes of hydrogen and one of oxygen combine to produce two volumes of water vapor.

"The weights of unit volumes of hydrogen, oxygen and dry air are accurately known, from which the specific gravity of aqueous vapor is found to be 0.6221."

The compared figures from various sources were submitted to Dr. Marvin, but he replied that "The Weather Bureau has not attempted to measure the quantity desired directly; in fact, the difficulty of experimentally maintaining a condition of absolute saturation and avoiding supersaturation, or, mechanically suspended moisture on the one hand and superheating on the other, is so great as to perhaps render the results thus obtained less acceptable than the theoretical values."

We must therefore accept these figures as generally recognized throughout the United States and at least as well established as our purpose requires.

In the next place a graphic method of calculation was desired, for rapidity and freedom from gross error, much more dangerous than slight inaccuracy. Also it was sought to visualize as far as possible what actually occurred to simplify comparison. A number of trials proved it far more satisfactory to disregard entirely the question of volume until it finally became necessary to calculate cross sections of air ducts, passages, etc.

A great gain was made by regarding "humidity" as "the pounds of water carried by one pound of air (or equivalent weight of other gas having the same volume) when saturated at a given temperature and pressure," and regarding the "percentage humidity" as "the weight of water actually carried by a pound of air divided by the maximum which could be carried by that pound of air under the same conditions."

This suggested as a substitute for specific heat something which we called the "humid heat" namely "the B. T. U. required to raise 1° F. one pound of air, plus whatever water vapor it might carry when saturated at the temperature and pressure, and a "percentage humid heat" varying regularly with the "percentage humidity" between that of air alone and that of the saturated mixture corresponding to the same conditions.

Similarly we obtained a new "humid volume," i. e., the volume of one pound of air when saturated under known conditions, and a corresponding "percentage humid volume" varying with the percentage of saturation between the specific volume of 1 lb. of dry air and the volume of 1 lb. of air saturated under the same conditions. We use the usual "density" plotted as shown and a "percentage density" (which does *not* vary proportionally with percentage humidity) only for calculating velocities in $V = k\sqrt{h\frac{d-d_1}{d}}$, for gravity circulation plants where k is always uncertain and damper regulation can be provided.

METHODS OF CALCULATION SIMPLIFIED.

It has been simply delightful to find the ease and facility with which calculations could be carried out when dealing with conditions thus defined.

Given a mixture (let us say saturated 90°), all we need to do for the heat capacity is to pass horizontally across to the "humid heat" curve (See Humidity Chart*), and if we want the heat capacity of any unsaturated mixture we find the corresponding temperature and per-

*This chart may be found in the pocket in the back cover of this volume.

centage of saturation, dropping vertically downward (merely a change in temperature) until we reach the saturation curve, and then horizontally across to the heat capacity of this saturated mixture. If we want the volume or density of any saturated mixture it is directly given by horizontally crossing to the "humid volume" or "density" curves.

One difficulty (not yet overcome in any other way so far as the writer has been able to learn) is presented by the question: "How much moisture will a saturated (or unsaturated) mixture, which has been heated to a certain temperature and is used for the drying of any material, take up before it becomes saturated (or 90% or 80% saturated, if we prefer) and to what temperature will it fall?" It is necessary, at present, to assume the specific heat of water vapor as constant,* 0.475, though there is both theoretical and experimental evidence that under these conditions it acts as superheated steam with a variable specific heat.

But assuming it constant, the law of cooling is obviously

$$\frac{dx}{dt} = \frac{1.438\ S}{1601 - t}$$

in which x represents the weight of water per pound of air, t represents the temperature (F.) at which evaporation is stopped, and S the specific heat of the mixture which we are heating and which is to be cooled by the evaporation it causes. But we have not any similar equation to express the line of saturation, 90% saturation or any other degree, and we cannot solve our problem mathematically. The latest German works on this subject give us nothing but a clumsy method of interpolation which requires a preliminary calculation of cumbersome tables and repeated trial calculations to select values which will approximately satisfy the two requirements.

We can, however, represent the direction of this "cooling by evaporation" graphically by straight "lines of cooling." It is apparent that no matter what the maximum temperature may be, if the condition of our preliminary mixture is represented by a point on any one of the curves of percentage saturation, the action of heating it is fully portrayed by elevating that point directly upward to the line of maximum temperature (neither its specific heat nor "humid heat" is changed).

* "Specific Heat and Total Heat of Superheated Steam," George A. Orrok, "Power," Aug., 04, pp. 426.

The direction of its fall in cooling $\left(\frac{dx}{dt}\right)$ will be the same no matter whether saturated at 75°, or 50% saturated at 96°, dependent upon its original air and water components expressed by the distance from the axis of Y (as governed by the numerator 1.148 S) and upon the temperature where it finally ends up in the course of its cooling (as governed by the denominator 1601-t). In considering the cycle it is perfectly correct to assume all the evaporation to have taken place at this final temperature.

We have therefore drawn for various final temperatures on our diagram a series of straight diagonal lines on the same Humidity Chart. representing $\frac{dx}{dt}$ for various initial mixtures, the water content of which is given by the distance from the Y axis where the left-hand end of each line ceases. On the left-hand side of the curve, owing to the slight difference of inclination of corresponding lines for successive final temperature, it is necessary to draw only one of these fan-shaped sets of lines and these need have been drawn only for each successive 10° of temperature. Here the saturation curves show that the temperature varies rapidly and water content (with corresponding specific heat) varies slowly. On the right hand portion of the curve where the variation of "water absorbed" (and of specific heat is greater, they are needed every 5°.

The lines for intermediate points can be drawn if desired, but it will be noted that a difference of 5° produces a difference of value of $\frac{dx}{dt}$ of about $\frac{1}{2}$ of 1%. This is a little difficult to determine by the eye on the angles, but is readily perceived in the accompanying tables (Table Ic*) if we compare the numbers in successive columns. For instance, the mixture saturated at 25°, we find respectively at 50° and 55° final temperatures, a variation of 7 divided by 2215, or 0.3 of 1%. For a mixture of 100° we find a variation of approximately 8 divided by 2509, or 0.3 of 1%. Selecting even the more sensitive mixture for 160° we find nearly as close an agreement, a variation of 13 divided by 3800.

Now it is apparent that with these lines upon our curve we may take any given mixture which is to be heated (whether saturated or not, to start with), run up the vertical to the maximum allowable temperature and, selecting from the nearest group of lines of cooling that one which starts from the nearest position with reference to the

*This table may be found in the pocket in the back cover of this volume.

Y axis, we may follow down parallel to this to the saturation curve.

If we are not considering the complete saturation, but only the 70% saturation of the final exit mixture (before cooling and condensation), this is only a first approximation. Upon noting at what temperature the diagonal intersects the curve of 70% saturation we must then redraw our incline, parallel to the incline corresponding to this mixture for the nearest final temperature to the one thus discovered.

EXAMPLE SHOWING USE OF CURVES.

As an illustration of the use of these curves, assume 50 lbs. per minute of water to be removed at a temperature not exceeding 110° F., with available air at 80° F. and 90% saturated. Assume the material to be so distributed and exposed that the air will leave the dry room at 80% saturation. How much air will be required? What will be its final temperature, etc.

On the chart we find 80° F. ordinate crosses the 80% humidity dotted curve at an abscissa of .0200 lbs. water per lb. of air. If heated to 110° the change of condition is represented by increased ordinate with no change of abscissa (absolute water content), the point rising vertically to 110°, where we find it between 30% and 40% humidity curves, or approximately 34% saturated.

On exposure to the material being dried, the air will cool and take up moisture, changing its condition parallel to the inclined straight line to the immediate right of the point, .0200 lb. 110°.

This diagonal shows that it will be 50% saturated at 101°, 70% saturated at 96°, and 80% saturated at 90°, with an abscissa of .0248 lbs. water per lb. of air, having picked up .0248 — .0200 = .0048 lbs. water per lb. of air.

To remove 50 lbs. water per minute would require 50 ÷ .0048, or about 10,000 lbs. of air per minute. To ascertain the heat required for this entering air we require the heat capacity of air at 80°, 90% saturated.

Starting from the same point as before, we drop to the 100% saturation curve, and find that our mixture has cooled to 77¼° F., and passing on the horizontal of 77¼° toward the left, to the Humid Heat curve, we find that each pound of air requires .248 B. T. U. per deg. F. to heat it and its water of saturation. We have then .248 × (110—85°) × 10,000 = 62,000 B. T. U. per minute.

To find the volume of 10,000 lbs. of air, let us say at the exit, where each pound is carrying .0248 lbs. of water with it and is 80% saturated, we have only to pass across from the point 80%, .0248 lbs.,

90° F. (where we ended the first operation), along the horizontal of 90° to the Specific Volume and the Humid Volume curves. The specific volume of dry air at 90° is 13.86, that of saturated air (Humid Volume) 14.55, and 80% of this difference is .69 × .8 = .552 added to the volume of dry air = 13.86 + .55, or 14.41 cu. ft. per lb. = 144,410 cu. ft. air per minute at the exit.

The lines at present shown upon the sheet have amply sufficed for all purposes of practical design and have made it possible almost at a glance to select the conditions best suited to a given problem. They show vividly, for instance, the great advantage secured by applying heat between successive partial saturations by progressive exposure to the material being dried,—also the enormous economy of restricted ranges of temperature.

Finally we are developing therefrom, with little labor of calculation, a series of curves which, it is hoped, may be presented on another occasion, showing for every 10 deg. F. entrance temperature, the maximum conditions of efficiency assuming various saturations of air before and after passing over the material. And a locus of maximum efficiency for these entrance and exit assumptions.

The auxiliary curves, Sheet No. 2,* are intended to simplify calculations of heating pipes, and present a graphic solution of the law of Dulong and Petit, as modified by Péclet & Box.* The use of the curves is extremely simple and is shown by arrows. They enable us to obtain the two components, radiation and convection loss, from pipes ⅛" to 12", U. S. Stand. size, per foot of length singly or in any of the ten positions which they may occupy in a bank. The fundamental basis of these calculations (0.64 B. T. U. radiation) and (0.95 B. T. U. convection) are not accurate by several per cent., and cannot remain constant as the pipes rust or gather dust. No effort has, therefore, been made to secure greater accuracy than given in the figures of Box. A safety factor has simply been added to the result given by the curves, and the size of this factor is being gradually reduced by experience. In our designs hitherto, the velocities of gases across the heating pipes has always been practically that of natural circulation, and no provision is shown here for variable velocities. It can easily be added by a single inclined line, if desired.

The derivation of these curves is as follows:

Table 2a is self explanatory, and merely serves to assemble together the general data required to begin the calculation of pipe

*This chart designated Loss of Heat from Pipes may be found in the pocket in the back cover of this volume.

radiation and convection, Col. IV being obtained by plotting Box's constants and interpolating for outer diameters of U. S. Stand.

Table IIb* is the ordinary convection table usually applied to the convection factors of Col. V., Table IIa, except that the factor for each temperature difference is first multiplied by the temperature difference in temperature. These results (Table IIb) for each convection factors corresponding to each size of pipe. These, therefore, give directly the B. T. U. per hr. of 1 ft. of actual U. S. Standard pipe. (Surface area of 1 ft. of pipe $\times$ Box's factor for given diameter, $\times$ factor of correction for given difference in temperature, $\times$ the difference in temperature). These results (Table IIb) for each standard size pipe are plotted, with Temp. Diff. as ordinate and B. T. U. per hr. as abscissae in the lower half of Curves II.

The presentation of Radiation is somewhat complicated by the fact that the correction factors vary both with temperature and with difference of temperature. These correction factors are represented by the fan-shaped set of curves on the upper half of the diagram. To avoid one useless operation, all the factors at various temperatures are first multiplied by their respective temperature differences, giving Table IIc (Radiation). These results were temporarily plotted with differences of temperature as ordinates and temperatures as abscissae. All the values for 18°, 36°, etc., were connected by curves, and intermediate points for every 10 deg. of temperature were read off and tabulated Table IId (Radiation). If, now, this new factor be multiplied by the product (Col. VI., Table IIa) of the coefficient of radiation (.64 B. T. U. per sq. ft. per hr.) and the area of the single foot of the given size of pipe (Col. III., Table IIa), we have the radiation in B. T. U. for one foot of isolated pipe. Graphically, this multiplication is carried out as indicated by the arrows on Curve II.

But it is frequently desired to use pipes in banks wherein position greatly effects radiation, though not influencing convection. Modified factors, reduced in proportion to the radiating angle obscured by the other pipes of the bank, are therefore calculated (assuming Crane's Standard malleable return bends are used for assembling) by the method indicated in Table IIe (Radiation) for the various possible positions indicated by numbers 1-10 on the diagram accompanying the curves. These various factors for the isolated and for the various partly obscured positions are assembled for easy reference in Table IIf (Radiation) also given on the curve sheet. The point to which the diagonal for this graphic multiplication should be drawn is

*This table may be found in the pocket in the back cover of this volume.

TABLE II a (General).

Nominal Pipe Diameter. in inches.	Outside Diameter U. S. Stand. in inches.	Outer Surface per Foot of Length, in Sq. Ft.	CONVECTION: Box's Factor B. T. U. per Sq. Ft. per Deg. per Hr.	CONVECTION: B. T. U. per Ft. Length per Deg. per Hr. III × IV.	RADIATION: Radiation Factor for Iron .64 × Col. III.
I.	II.	III.	IV.	V.	VI.
⅛	.405	.106		.125	.068
¼	.540	.141		.150	.090
⅜	.675	.177		.172	.113
½	.840	.219	.926	.204	.140
¾	1.050	.275	.870	.239	.176
1	1.315	.344	.822	.283	.220
1¼	1.66	.435	.770	.334	.278
1½	1.9	.497	.736	.366	.318
2	2.375	.622	.680	.423	.378
2½	2.875	.752	.632	.475	.481
3	3.500	.916	.595	.545	.586
3½	4.000	1.005	.574	.578	.643
4	4.500	1.178	.527	.622	.754
4½	5.000	1.309	.544	.713	.838
5	5.563	1.456	.533	.776	.932
6	6.625	1.733	.515	.894	1.109
7	7.625	1.996	.501	1.	1.277
8	8.625	2.257	.491	1.105	1.444
9	9.625	2.519	.484	1.218	1.612
10	10.750	2.817	.478	1.345	1.803
12	12.75	3.333	.469	1.56	2.133
18	18.	4.717	.455	2.13	3.019
24	24.	6.289	.447	2.81	4.025
36	36.	9.434	.438	4.13	6.038
48	48.	12.563	.434	5.45	8.040

indicated on the main guide line, but only a few of the diagonals to these points have been drawn, as our own particular interest centres mainly on combinations of 1″ pipe. The other lines can easily be drawn when required.

The simplified calculation of wall, ceiling and window losses was found to be well worked out in the curves by Mr. Harrison, published by the "Heating and Ventilating Magazine."

TABLE II c (Radiation).

Product of Radiation Factor for Pipes and Temperature Differences.

Mean Air Temperatures, Fahrenheit.

Difference in Temperature (Steam and Air) in Degrees F.	0° F.	32°	50°	59°	68°	86°	105°	122°	140°	158°	176°	194°	212°
	18	18.00	19.26	20.16	20.85	22.5	24.5	27.5	28.4	30.6	33.3	35.8	38.7
	36	37.1	38.9	41.8	43.6	46.8	50.4	54.75	60.5	63.4	68.8	74.2	80.4
	54	57.8	62.6	64.8	67.5	72.9	78.3	85.7	91.8	98.8	107.4	115.4	124.7
	72	80.6	86.4	90.1	93.6	100.7	109.3	118.1	126.7	136.8	149.0	160.5	172.8
	90	104.3	112.4	117.8	122.3	131.3	142.2	153.8	165.5	170.0	193.5	209.5	226.0
	108	130.7	141.4	146.8	153.5	164.2	178.3	192.3	207.5	223.5	246.5	261.5	283
	126	158.7	171.3	178.9	186.5	189.0	216.5	234.3	252	272.2	295	317	343
	144	190	204.5	213.2	222	237	258	279	299	323	351.7	380.5	408
	162	222	240	249.5	259.2	280.5	301.5	327.5	352	379	412	444	480
	180	259	279	290	302	326	351	380	409	443	479	517	558
	198	297	321	335	346	374	404	438	472	507	551	594	642
	216	341	365	380	495	426	460	501	536	579	628	676	731
	234	384	414	431	445	482	534	569	590	656	709	768	810
	252	431	467	484	504	542	588	635	683	736	789	864	933
	270	483	521	543	565	600	659	713	767	826	897	962	1041
	288	544	585	611	634	682.5	737	801	861	927			
	306	571	613	639	666	717	775	836	899	971			
	324	671	723	756	784	849	911	985					
	342	742	801	834	868	934							
	360	817	883	922	958								
	378	904	972										
	396	989											

TABLE IId (Radiation).

Product Factors of Table IIc, Plotted and Rearranged for 10° Temperature Variations.

Temperature of Air in Degrees F.	Difference in Temperature (Steam and Air) in Degrees F														
	18°	36°	54°	72°	90°	108°	126°	144°	162°	180°	198°	216°	234°	252°	270°
30	17.85	36.8	57.4	80.	104.	129.5	157.	188.5	220.	255.	295.	339.	381.	427.	479.
40	18.55	38.5	59.9	83.	108.	135.	164.	196.5	230.	267.	307.	351.	396.	446.	500.
50	19.3	40.2	62.6	86.4	112.	141.	171.5	205.	240.	279.	320.	365.	414.	466.	522.
60	20.1	42.1	65.3	90.1	117.	147.5	180.	214.	250.5	291.5	335.	381.	433.	487.	545.
70	21.	43.8	68.1	94.	122.	154.	188.	224.	262.	304.	350.	398.	451.	508.	569.
80	21.9	45.7	71.0	98.	128.	161.5	196.	234.	273.	317.	366.	415.	471.	530.	593.
90	22.8	47.6	74.	102.2	134.	168.5	204.5	244.	284.	331.	382.	434.	491.	553.	619.
100	23.8	49.6	77.2	106.7	140.	176.	213.	254.5	296.	345.	398.	453.	512.	577.	647.
110	24.9	51.8	80.6	111.4	146.	183.	222.	265.	309.	360.	416.	472.	536.	602.	675.
120	26.	54.2	84.2	116.3	152.	191.	231.5	276.	323.	376.	434.	491.	561.	628.	705.
130	27.2	56.6	87.9	121.4	159.	199.	241.	287.	337.	392.	453.	513.	586.	655.	736.
140	28.4	59.1	91.7	126.7	166.	207.5	252.	299.	352.	409.	472.	536.	611.	683.	767.
150	29.7	61.6	95.8	132.3	173.5	216.	263.	312.	368.	427.	491.5	559.	636.	712.	798.
160	31.0	64.2	100.	138.2	181.	225.	274.	325.	384.	446.	513.	583.	663.	741.	832.
170	32.4	67.0	104.4	144.3	189.	236.	286.	339.	401.	466.	536.	608.	690.	771.	870.
180	33.8	70.0	109.	150.7	197.	247.	299.	354.	419.	487.	559.5	634.	718.	802.	919.
190	35.2	73.	113.6	157.3	206.	258.	313.	370.	437.	508.	584.	663.	746.	834.	
200	36.7	76.4	118.5	164.1	215.	269.	326.	385.	456.	530.	610.	694.	775.	866.	
210	38.2	80.	123.5	171.0	224.	281.	340.	403.	476.	553.	637.	725.	804.	899.	
220	39.8	83.7	128.5	178.	233.	292.	354.5	420.	496.	576.	665.	757.	832.	933.	
230	41.4	87.5	133.6	185.2	242.5	304.	369.5	437.	517.	600.	694.	789.	860.	967.	
240	43.1	91.5	138.7	192.6	252.	316.	384.	455.	538.	625.	723.	822.	889.	1001.	
250	44.8	95.6	143.9	200.1	262.	328.	399.	473.	560.	650.	752.	855.	916.		
260	46.6	100.0	149.1	207.7	272.	340.	414.	492.	582.	675.	782.	888.	950.		

TABLE II e (Radiation).

Pipe			Return Bend	Angle of Obscuration		Distance	Other Angle of Obscuration	
Nominal Size	Outside Diameter	Radius	c-c d	sine r/d	α	c-c-other pipes $d' = d\sqrt{2}$	Sine $r/d\sqrt{2}$	α'
½″	.840	.420	1½″	.2800	16° 16′	2.1225	.1974	11° 23′
					976′			683′
¾″	1.050	.525	2″	.2625	15° 13′	2.830	.1848	10° 39′
					913′			639′
1″	1.315	.655	2½″	.2628	15° 11′	3.537	.1851	10° 40′
					911′			640′
1¼″	1.66	.830	3″	.2767	16° 4′	4.245	.1955	11° 16′
					964′			676′
1½″	1.9	.950	3½″	.2712	15° 44′	4.952	.1919	11° 4′
					944′			664′
2″	2.375	1.188	4″	.2973	17° 18′	5.660	.2099	12° 8′
					1038′			728′

Ratio, Total All Unobscured Angles ÷ 360°, in Various Position #1–#10.

Nominal Pipe size	Position 1 $\frac{360-2\alpha}{360}$	Position 2 $\frac{360-4\alpha}{360}$	Position 3 $\frac{315-3\alpha-3\alpha'}{360}$	Position 4 $\frac{315-3\alpha-\alpha'}{360}$	Position 5 $\frac{315-\alpha-\alpha'}{360}$	Position 6 $\frac{270-2\alpha'}{360}$	Position 7 $\frac{225-\alpha-\alpha'}{360}$	Position 8 $\frac{90-2\alpha}{360}$	Position 9 $\frac{180-4\alpha}{360}$	Position 10 $\frac{180-2\alpha'}{360}$
½	.909	.818	.644	.708	.798	.687	.548	.159	.319	.437
¾	.916	.832	.659	.719	.803	.691	.553	.165	.331	.441
1	.916	.832	.659	.719	.803	.691	.553	.165	.332	.441
1¼	.911	.822	.648	.710	.799	.687	.549	.161	.323	.438
1½	.913	.826	.651	.713	.800	.689	.550	.163	.325	.439
2	.904	.808	.630	.698	.793	.683	.543	.155	.308	.433

TABLE II f (Radiation).

Product (for various positions of each size of pipe) of Obscuration Factor × Co. 6 Table II a.

Nominal Pipe size	Insulated	Positions of Pipe in Bank (See Curve II).									
⅛″	.068										
¼″	.090										
⅜″	.113										
		1	2	3	4	5	6	7	8	9	10
½″	.14[illegible]	.127	.115	.090	.098	.112	.096	.077	.022	.045	.061
¾″	.176	.161	.145	.116	.126	.141	.122	.097	.029	.058	.078
1″	.220	.202	.183	.146	.159	.177	.153	.121	.036	.073	.097
1¼″	.278	.253	.228	.180	.198	.222	.191	.152	.045	.090	.122
1½″	.318	.290	.261	.207	.227	.254	.219	.175	.052	.103	.139
2″	.378	.342	.305	.239	.264	.300	.258	.205	.058	.116	.164
2½″	.481		4″	.754		6″	1.109		9″	1.612	
3″	.586		4½″	.838		7″	1.277		10″	1.803	
3½″	.643		5″	.932		8″	1.444		12″	2.133	

Similarly the capacity and drop in pressure in steam mains has been carefully worked out by E. C. Sickles, and published in "Power."

The design of the condenser remains for consideration. It is a surprising fact, but a most thorough search has revealed no data applicable to this case. We use banks of horizontal 1" pipe with water or brine circulating within them. If they were merely cooling air we could find ample data for design. They would transmit about 1.5 B. T. U. per square foot per degree per hour. If they were condensing practically pure steam some quite recent work would be available. They would transmit from 150 to 300 B. T. U. per square foot per hour. But they do neither and yet they do both. A formula has been developed upon purely theoretical grounds similar to those of the law of mass action. It will be submitted later (not as a solution, but as a view for criticism and test), together with examples showing how far it is justified by actual practice.

Curve I.—Humidity.

Curve II.—Heat losses from steam pipe.

Curve III.—See Heating & Ventilating Magazine supplement September 16, 1907, B. S. Harrison.

Curve IV.—"Power," May 26, 1908, page 812.

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